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To determine the performance and physiological effects of various physical conditioning programs in women, total body, upper-body resistance training groups, field training and aerobic training groups (n = 11 to 21) were examined over 6 months. A normative group of men (n=100) were also tested. Adaptations in muscular strength, size, endocrine function, and immune cell changes can be seen in three months of training. Training responses are very specific to the type of program used, the movements trained, and the way exercises are performed in the training session (e.g., slow versus explosive). It appears that a periodized resistance training program using loads from ≤ 8 RM and performs explosive exercises is the most effective in eliciting gains in all fitness and military task tests. An aggressive field training program utilizing explosive plyometrics and partner exercises would be effective maintenance program in the field. Load carriage capabilities in resistance trained women equaled the men's. Aerobic training alone is not effective in making gains in any of the military performance tasks. A total training program is effective to enhance physical performance in military tasks without any direct practice of the task (e.g., box lift, ruck sack carriage) reducing risk of injury.

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William J. Kraemer 18 Oct 99

PI - Signature Date

TABLE OF CONTENTS

INTRODUCTION

The prevalence of women engaged in physically demanding military occupational specialties continues to increase as the armed forces strive to fully integrate women into the United States Army. Specifically, many military occupational specialties (i.e., different work tasks) require muscular strength and long-term load bearing capabilities up to 40 kilograms deeming exceptional strength and durability necessary for women officers (Sharp 1994). An understanding of the trainability of various physical fitness components needed by women for successful service in the US Army is therefore essential. This investigation evaluated the influence of physical training programs (i.e., resistance and endurance training) over a six month training period in women with an experimental design to partial out the role of upper body resistance training on physical performance. In addition, we examined various underlying biological aspects of physical conditioning in various groups (for specific questions) to better understand the adaptations which may mediate some of the alterations in physical performance. In addition, we examined the physical performance characteristics of women in comparison to a typical non-resistance trained control group of men to better understand the context of the women's absolute performances and gains made with training.

STATEMENT OF WORK

1. Pilot test all experimental variables and equipment

2. Recruit, gain informed consent, medically screen, familiarize, and pre-test women and men

3. Match, balance and randomize women into subject groups

4. Perform training familiarization

5. Initiate supervised physical training programs

6 Perform data collection at 0 (T-1),3 (T-2) and 6 (T-3) months for training groups

6. Perform biochemical and immunological assays

8. Perform magnetic resonance image scans of upper and lower limb musculature

9. Perform strength test evaluations

1. Coordinate with the United States Army Research Institute's Military Performance Division military relevant physical performance task tests at Penn State.

2. Develop computer data base management scheme and perform data entry and analyses over the course of the experimental period.

3. Utilize phase one weight room data to develop optimal strategies for program design of "field training" resistance program for year three.

13. Analyze data set and provide appropriate reports, physical training recommendations, and scientific publications on physical training of women.

METHODS

Experimental Approach. In order to determine the performance and physiological impact of different resistance exercise programs in women and to further elucidate the role of upper body training on physical performance, two different types of exercise protocols were used and each program was divided into a total body and upper body group. To determined if subtleties of one type of resistance training protocol was more effective than another one group emphasized strength and power while the other group emphasized muscular strength and local muscular endurance. The protocols differed based upon their loading ranges used. In addition, to give the data context, a typical aerobic training group was used as a type of control group. In addition, we wanted to determine the effectiveness of a carefully designed exercise program that could be used in the field where no formal training equipment was available. This was called a field training group. We also utilized various matched groups of control subjects (6 to 10 subjects) to provide for necessary reliability data and seasonal control data when needed for certain experimental variables. Finally, unique to this study we also tested a group of men to act as gender matched controls for physical performance test comparisons.

Subjects. Previously untrained women were informed of the potential risks associated with this investigation and signed an informed consent document approved by the Institutional Review Board at The Pennsylvania State University and by the Human Use Review Office of the Army Surgeon General. All women were medically screened prior to study inclusion to eliminate those with potential

orthopedic, endocrine, or other disorders that would be contraindicated for a heavy-resistance training program. Only women receiving a negative pregnancy test were permitted to begin the study. Women were initially tested (T1) and then randomly assigned to either a total strength/power resistance (TP), upper strength/power resistance (UP), total hypertrophy resistance (TH), upper body hypertrophy resistance (UH), field calisthenics/ballistic plyometric (FLD), or an aerobic/light resistance band training group (AER). Again, some tests were performed in control (non-exercise groups) to provide for reliability data for a specific comparison. Subjects characteristics are shown in Table 1.

Subjects were initially matched (age, height, body mass, and 1-RM squat and bench press performance) and then randomized into an experimental group. A total of 120 women were recruited for the investigation along with non-exercising controls for certain tests. After attrition, the group "n" sizes for the 6 experimental groups in this investigation were: TP = 18, UP = 21, TH = 21, UH = 19, FLD = 14, and AER = 11. The majority of the drops occurred during the early phases of the study due to reasons not related to the investigation (i.e., lack of interest or other time commitments). Only one injury (plantar tendon inflammation) after 3 months caused a subject to drop from the study. In addition, any subjects with eating disorders or symptoms of them were screened and referred to proper medical professionals but were not allowed to participate in the study. A group of physical active and healthy men (n=100) who were "not resistance trained" were also recruited for the investigation to gain cross-sectional data for comparison with the women's performance capabilities. They were screened to match the typical size of soldiers in the military to make the data more appropriate for comparisons to the women's performance (Fitzgerald et al., 1986).

Table 1. Subject characteristics by group.

Group	Age, yrs	Height, cm	BM, kg	% Fat
TP (n = 18)	22.4 ± 3.5	163.7 ± 7.5	64.1 ± 8.80	25.8 ± 5.90
UP (n = 21)	22.7 ± 4.0	165.5 ± 7.2	66.7 ± 10.7	25.5 ± 6.10
TH (n = 21)	23.8 ± 3.7	165.4 ± 5.4	63.2 ± 7.00	23.9 ± 5.00
UH (n = 19)	23.5 ± 3.7	166.7 ± 6.2	65.7 ± 12.1	26.3 ± 5.30
FLD (n = 14)	22.6 ± 4.4	166.5 ± 7.8	67.9 ± 12.2	29.4 ± 5.60
AER (n = 11)	24.8 ± 4.3	165.7 ± 5.6	69.1 ± 10.6	30.8 ± 8.10
MEN (n=100)	22.1 ± 2.7	176.9 ± 6.0#	78.7 ± 9.4#	16.5 ± 6.4#

Values are means ± SD, BM = Body Mass, 1-RM = One-Repetition Maximum, Sq = Squat, Bp = Bench Press
TP = Total Strength/Power, UP = Upper Strength/Power, TH = Total Hypertrophy, UH = Upper Hypertrophy
FLD = Field, AER = Aerobic, Except for age, men are $P < 0.05$ from all women's values.

Physical Training Overview. Subjects in the four resistance training groups participated in a 24-week periodized, heavy-resistance training program divided into two 12-week macro-cycles, each consisting of three, four-week mesocycles (Fleck and Kraemer, 1997, Kraemer & Koziris, 1992). Subjects in the FLD group performed a 24-week periodized, calisthenics/ballistic plyometric training program designed to simulate an "in the field" training scenario (Häkkinen, 1993). The FLD training program also was divided into two 12-week macro-cycles, each consisting of a four and an eight week mesocycle. The resistance training and FLD training groups also participated in their respective training programs on three alternating days per week, followed by 20 to 25 minutes of aerobic-endurance exercise. Subjects in the AER group performed 25 to 35 minutes of aerobic exercise with very light and controlled slower speed resistance band (Jump Stretch, Boardman, Ohio) exercises on three alternating days per week. The aerobic training program was designed so as not to interfere with strength and power development while helping to improve endurance capabilities (Volpe et al., 1993). All training programs

included a two-week active rest period between the two 12-week mesocycles. During this time, subjects were permitted to participate in recreational physical activity only (i.e., racquetball, skiing, outdoor cycling, camping, etc.). Women were tested before (T1) and after the first (T2) and second macro-cycles (T3) for military relevant work tasks, resistance exercise performance, army physical fitness tests, thigh and arm muscle cross-sectional areas, body composition, and blood assays around a 6 X 10 RM squat protocol. Testing was undertaken during the follicular phase of the menstrual cycle for hormonal and immune testing per previously documented methods (DeSouza et al., 1989). All groups were matched for menstrual cycle patterns. All women were nutritionally screened and provided with ongoing nutritional counsel and assessments over the course of the study as to eating proper amounts of calories, protein, carbohydrates, and fat by a registered dietitian (RD). One of the military work tasks (i.e., 2 mile load run) and the U.S. Army physical fitness tests were administered only at T1 and T3. The subjects in this study did not train with any of the military work tasks (i.e., box lifts, or ruck sack carry) as we wanted to see how conventional training programs transferred their effects to these tasks. This was different than prior work with this type of long-term training (Harman et al., 1998).

Overview of Experimental Variables

Military relevant work tasks used in this study were the maximal amount of weight that can be lifted one time in a box from the floor to a height of 1.32 m (1-RM box lift in kg), the number of boxes (20.45 kg) that can be lifted from the floor to a height of 1.32 m in 10 minutes (repetitive box lift in number of repetitions), and two mile load carriage (34.1 kg) run time (2m load run in s). The

resistance exercise performance variables included 1-RM squat, bench press, and high pull (kg); squat jump power (30, 60, and 90% peak power in Watts); bench press throw power (BP peak power in Watts); and the number of squat repetitions that can be completed at a standard cadence with 45.36 kg (squat endurance in number of repetitions). The U.S. Army physical fitness test variables included the number of push-ups performed in two minutes, number of sit-ups performed in two minutes, and 2 mile run (2m run) time recorded in seconds. Muscle cross-sectional area assessment variables were mid-thigh and mid-upper arm muscle cross-sectional areas in the resistance training groups. Body composition assessment included body mass (kg), fat mass (kg), fat-free mass (kg), % body fat as determined using skinfold measurements (SF % BF), and % body fat as determined using circumference measurements (Fitzgerald et al., 1986). Immune cell responses were determined for specific group comparisons. Hormonal concentrations were determined for specific groups including total testosterone, free testosterone, cortisol, growth hormone(s), and IGF-1.

Anthropometry and Body Composition

Height and weight were determined with a physician's scale. Circumferences were obtained at four sites with a tension controlled tape at the wrist, forearm, neck, and hip. Skinfold thicknesses were obtained at seven sites with a Lange skinfold caliper at the chest, mid-axillary, triceps, sub-scapular, abdominal, supra-iliac, and thigh following the procedures described by Lohman et al. (1988). All circumference and skinfold measurements were taken on the right side of the subject's body by a single trained and experienced investigator. Repeated trials were performed until two measures within 2 cm and 2 mm were obtained for the

circumferences and skinfolds, respectively. The average of the two measures was reported as the value. To ensure inter-tester reliability, each subject was tested by the same investigator at each testing time point. The equation described by Jackson and Pollock (1978) was used to estimate body density (Jackson and Pollock, 1978). Skinfold % body fat (SF % BF) was subsequently estimated using the value obtained for body density and the Siri equation (Siri, 1961). Fat-free mass was determined by subtracting fat mass from body mass. Circumferences were used with body mass and height to estimate percent body fat via U.S. Army methods (ARMY % BF) described by Fitzgerald et al. (1986).

Magnetic Resonance Imaging

The cross-sectional areas of the mid-thigh and mid-upper arm were measured by MRI using a 0.5 Tesla Picker Vista MR with MR6B software. Images were obtained by alteration of the spin-lattice or longitudinal relaxation time. Weighting of the longitudinal relaxation time was with repeat time (500 ms) and echo time (13 ms). Radio frequency (90 degrees) power absorption was 0.028 watts/kg. Fifteen transaxial images of 1 cm slices were obtained equidistantly between the base of the femoral head and mid-knee joint of the thigh, and the superior head of the humerus and mid-elbow joint of the upper arm. The dominant limbs were used for the investigation. The thigh was supported under the knee so as to be parallel to the MRI table, and the feet were strapped together to prevent rotation. The arm was positioned in a moderately internally rotated position, with the palm of the hand on the thigh, and support was placed under the shoulder and elbow so that the upper arm was parallel to the MRI table. Sagittal images of the thigh and upper arm were obtained, and a 15 slice grid was placed over the sagittal images

and the transaxial images were obtained. For T1, T2, and T3 analysis, mid-thigh and mid upper arm images were used. For the thigh, slice 8 was used (slice 1 being the base of the femoral head); for the upper arm, slice 9 was used (slice 1 being at the superior humerus). One slice lower was used for the upper arm to ensure proper inclusion of the brachialis muscle. Tissue cross-sectional area was obtained by displaying the images through Maxitron displayer and Adobe program, and using the NIH 1.55.20A Image Analysis pixel counting program. The cross-sectional areas reported for this investigation are bone-free. Reliability of this measurement technique for the investigators performing the measurements was determined in this investigation to be R=0.99.

Military Relevant Work Tasks

1-RM Box Lift. The 1-RM box lift required the subject to lift a metal box (0.47 m X 0.23 m X 0.31 m) from the floor to a height of 1.32 m. Proper lifting technique (i.e., straight back lifting technique), using primarily the lower limbs to perform the lift, was recommended but not required. However, no contact with the body was allowed for a good lift (i.e., subject could not work the box up the body but rather have to lift it up and push it out onto the truck landing in a single movement). The 1.32 m height was specifically chosen because it is also the height from the ground to the bed of an Army utility truck. Thus, this functional lifting task was one that a soldier would be likely to encounter during a typical work day. Three to five trials were permitted with mass incrementally added to the box until the subject could not successfully complete the lift. Upon failing an attempt, the subject was given a final attempt with a weight that was slightly less than had been used in the failed attempt, but heavier than the highest successful attempt.

Performance was measured as the total kilograms lifted during the maximum attempt.

Repetitive Box Lift. The repetitive box lift consisted of the maximum number of boxes (mass = 20.45 kg) that could be lifted from the floor to a 1.32 m platform in 10 minutes. Once again, proper lifting technique (i.e., straight back lifting technique), using primarily the lower limbs to perform the lift, was recommended but not required. However, no contact with the body was allowed for a good lift (i.e., subject could not work the box up the body but rather they had to lift it up in one movement and push it out onto the truck landing in a single movement). The subject moved at a volitional pace between two platforms that were placed 2.4 m apart, lifting one box at a time onto each platform. After each successful lift, two investigators returned the box to the floor while the subject was lifting the box at the other platform, etc.

2 Mile Load Run. The 2M load run consisted of the carrying of a 34.1 kg backpack (i.e., rucksack) for a two mile distance on an all-weather 400 m track. The rucksack consisted of an external frame with the load properly positioned within the rucksack. Upon command, the subject moved as fast as they could to complete the two mile distance, with the performance measured and recorded in seconds.

Resistance Exercise Performance Measures

All resistance exercise testing protocols were performed on separate days using the Plyometric Power System (Lismore, NSW, Australia). The Plyometric

Power System consisted of a Smith machine and barbell interfaced to an on-line computer system which allowed the accurate collection of strength and power data (Wilson et. al, 1991). Resistance was provided by the barbell which can only move in the vertical direction up and down two steel shafts along linear bearings attached to either end of the bar. This machine thus permits movements such as the squat to be performed in a dynamic, ballistic manner with minimal risk to the subject. The machine was connected to a rotary encoder that recorded the position and direction of the bar within an accuracy of 0.2 millimeters.

1-RM Squat, Bench Press, and High Pull. 1-RM testing included two warm-up sets of two to five repetitions per set estimated at 50 and 80% of 1-RM as determined by recent training experience. Subjects were permitted three to five attempts with two to three minutes recovery time between attempts until a 1-RM was attained (Kraemer et al., 1991; Kraemer and Fry, 1995). For successive attempts, the load on the bar was increased 2.5 to 12.5 kg depending upon the difficulty evidenced on the previous attempt. Upon failing an attempt of any of the 1-RM lifts, the subject was given a final attempt with a weight less than had been used in the failed attempt, but heavier than the highest successful attempt. Performance for all 1-RM tests was measured in kilograms (kg).

A successful attempt in the squat required descending into a parallel squat position by flexing the knees and hips until the trochanter head of the femur reached the same horizontal plane as the superior border of the patella (Fry et al. 1991). The subject then returned to a standing position by extending the knees and hips without excessive rounding of the back. For the 1-RM bench press, the

subject lowered the bar under control until it lightly touched the chest (i.e., bouncing the bar off the chest was not permitted). The subject then lifted the barbell back to a straight-arm position while keeping his or her feet and hips in contact with the floor and bench, respectively. For the 1-RM high pull, the subject stood upright and gripped the barbell with an overhand grip slightly wider than the shoulders. With the arms extended at the sides of the body and feet positioned so that the instep of each foot was directly under the bar, the subject extended his or her hips powerfully to full extension, rose onto the toes, shrugged the shoulders, and pulled the bar to medial clavicular height using the entire body movement. Once the subject had begun upward acceleration of the bar, the investigator applied the brake to the Plyometric Power System. By applying the brake, the bar was prevented from descending but its upward movement was not interrupted, thus stopping the bar at the apex of the pull and allowing the investigator to judge the height of the bar. For a successful attempt, the bar must have reached the height of a standing subject's medial clavicle. For consistency in the judgement of successful attempts, braking of the Plyometric Power System, and measurement of the bar height, one investigator was assigned to each of these performance tests and subsequently conducted all trails of all subjects throughout the study.

Squat Jump Power. Following a warm-up set, subjects performed three attempts of squat jumps at each of 30, 60, and 90% of their previously determined 1-RM squat value with two minute rests between attempts. Thirty percent of the 1-RM was chosen as a testing intensity since mechanical power is maximized near this value (Wilson et al., 1993). Sixty and 90% of the 1-RM were used to provide a means to assess potential different training adaptations specific to the power (i.e.,

explosive, more aggressive movements with heavier training loads) versus hypertrophy (i.e., slower, more controlled movements with lighter training loads) modes of resistance training (Häkkinen, 1990; Kraemer and Koziris, 1992; Stone et al., 1981; Stowers et al., 1983; and Wilson et al., 1993). A trial in the squat jump required the subject to perform a parallel squat and, upon reaching the bottom position of the lift, to explosively extend the hips and knees accelerating the barbell mass upward with maximum power. Subject's were instructed to release the bar at the apex of the jump, allowing the bar to continue upward until the effects of gravity overcame its acceleration. Pushing the bar with the hands was not permitted and resulted in an unsuccessful attempt. Once the subject had begun upward acceleration of the bar, the investigator applied the brake to the Plyometric Power System which prevented the bar from descending but did not interfere with its upward movement. The resultant data were collected by the online computer system and were later analyzed for power output. From the three attempts at each intensity (i.e., 30, 60, and 90%), the one producing the highest power output was recorded as the peak squat jump power in watts (W).

Bench Press Throw Power. After a light warm-up, subjects performed three attempts of bench press throws at 30% of their previously measured 1-RM bench press with two minutes recovery between each trial. Thirty percent of the 1-RM was chosen as the resistance because mechanical power is maximized near this value (Wilson et al., 1993). The bench press throw required the subject to perform a bench press, lowering the bar to the chest and, upon reaching the chest, to throw the bar as high as possible with maximum power, releasing the bar at the apex of the movement. Again, the system's brake allowed for the stopping of the bar so that it did not descend toward the subject. The data were collected,

analyzed, and the highest power output trial was recorded as the peak bench press throw power (W).

Squat Endurance. The squat endurance test required repetitive squatting with an absolute load of 45.36 kg. The barbell was standardized individually for each subject to move exactly 0.36 m per repetition. Subjects squatted in accordance with the audio sound cue from a metronome at a rate of 37.5 repetitions per minute (0.625 repetitions per second). These specifications were employed to allow for an external power output of 100 watts during the test (Communications with Dr. E. Harman, USARIEM, Natick, MA). Performance was measured as the total number of repetitions performed.

U.S. Army Physical Fitness Test Measures

All three U. S Army physical fitness tests were conducted by the same investigator for all subjects at all time points according to the guidelines and procedures given in the U.S. Army physical fitness training manual (FM 21-20). For push-ups and sit-ups, subjects performed the maximum number that could be completed in two minutes. The starting position for sit-ups required the subject's to lie on the their backs, knees bent, feet flat on the floor, and hands interlocked behind the head. With the investigator holding the subjects feet, the subject raised his or her elbows passed the bent knees and then returned to the starting position. Subjects were not permitted to rest during push-up or sit-up testing. For the 2m run, performance was measured as the minimum time (sec) required to run 2 miles on an all-weather 400 m track. Ten minute rests were required

between U.S. Army physical fitness test parameters, conducted in the order push-ups, sit-ups, and 2m run.

Acute Exercise Test, Blood Samples, and Biochemical Assays

Blood Collection and Analyses.. Blood samples were obtained from a superficial arm vein pre- and immediately post exercise using a needle, syringe, and specialized vacutainers™. The acute exercise test consisted of 6 sets of 10 RM of squats using the Plyometric Power System with 2 minutes rest between sets. Blood samples were obtained at the same time of the day for each subject to limit the influence of any diurnal variations. Blood was drawn after an overnight fast and dietary intake was monitored and recorded across collection time points. Blood was centrifuged at 1500 x g at -4° C for 15 minutes. All serum and plasma samples were then distributed to appropriate preservative tubes and stored at -88° C until analysis. Hematocrit was determined in triplicate using a standard microcapillary technique. Hemoglobin was determined colorimetrically in duplicate using the cyanmethemoglobin method (Sigma Chemical Co., St Louis, MO, USA). Serum was obtained for total testosterone (TT), free testosterone (FT), cortisol (C), growth hormone(s) and insulin-like growth factor-1 (IGF-1).

Hormones were analyzed in duplicate using various immuno-assay techniques. Intra-assay variances were all <5% and inter-assay variance were less than 8%. Serum testosterone (TT) and free-testosterone (FT) and cortisol (C) were analyzed by single-antibody (solid phase) ^{125}I radioimmunoassays (Diagnostic Systems Laboratory, Webster, TX). Total IGF-1 was analyzed with ^{125}I

preliminary column extraction to separate IGF-1 from its binding proteins using a two site immunoradiometric ^{125}I assay (IRMA) (Diagnostic Systems Laboratory, Webster, TX). Antibody sensitivities were TT (0.14 nmol/L), FT (0.52pmol/L), and IGF-1 (< 2 nmol/L). Two molecular variants of growth hormone were analyzed in this study. Immunoreactive plasma growth hormone (IGH) was analyzed using an immunoradiometric monoclonal assay (IRMA) (Nichols Institute Diagnostics, San Juan Capistrono, CA) with one of the antibodies labeled for detection while the other was coupled to biotin. It had a sensitivity of 0.05 μg/L. Concentrations of biologically active growth hormone (BGH) were determined according to the method of Greenspan et al. (1949). Activities were compared to a standard bovine GH preparation (USDA bGH B-1 AFP 5200; 1.4 OI/mg, 0,5,15 and 45 μg total doses) and expressed in terms of purified pituitary human GH (3.0 IU/mg).

Fifteen ml of plasma was fractionated on a 100 cm long Sephacryl S- 100 HR sizing column (26 mm i.d.) and the resulting 100 tubes pooled into 3 larger fractions containing molecules with apparent molecular weights > 60kD (Fr.A): 30-60kD (Fr. B) and <30kD (Fr. C). Sephacryl columns were used ones for processing each of the 60 pre-AHRET plasma samples and the others for the 60 post-AHRET samples. Each of the 2 columns was calibrated using blue dextran (MW 200,000); BSA (MW 66,000); carbonic anhydrase (MW 29,000); cytochrome C (MW 12,400) and aprotinin (MW 6,500) that were provided in a molecular weight standards kit (Pharmacia, Uppsala, Sweden). Columns were washed with 0.05 NH_4HCO_3. pH 8.0 (1 column volume) between processing of each plasma sample and were recalibrated after 15 plasma samples had been processed. Regression analysis of these calibration curves (log MW vs Ve/Vo) yielded lines of the form y= - 1.069 + 6.1144 and y = -1.0196 + 6.0595. Correlation coefficients for these regressions were

0.997 and 0.996 respectively. In addition to the three pooled Sephacryl fractions, an aliquot of unfractionated plasma was also lyophilized before reconstitution in 10 ml of 0.001 M $NaHCO_3$, pH 8.0 and subsequent GH assay. In order to determine what effect lyophylization might have on GH measurements an aliquot of unfractionated plasma was not lyophilized and subsequently assayed by the Nichols IRMA.

An A LKB Model 1272 Clini gamma counter and on-line data reduction system (Pharmacia LKB Nuclear, INC., Gaithersburg, MD, USA) was used to determine immunoreactivity values. Plasma volume changes were calculated using hematocrit and hemoglobin values and the methods described by Dill and Costill (1974). Hormonal concentrations were not corrected for plasma volume changes. The plasma volume changes in this study pre- to post-exercise were less than 10%. No significant differences in plasma volume changes between groups or with training were observed.

Immunological Assessments. The immune system consists of leukocytes, organs and tissues that produce and store leukocytes, and a communication system that includes neural and endocrine influences and a wide variety of cell-signaling molecules. Leukocytes are transported from the tissues that produce them, to and from sites of storage, and to tissues in need of immune cell activity via the circulation. Measurements made using leukocytes collected from the blood at rest give some indication of the status of the immune system as a whole. However, caution is required in the interpretation of data from blood leukocytes, as they represent less than 5 percent of all leukocytes in the body and may not reflect the status of all immune cells. After particular stresses, such as exercise,

measurements made using leukocytes collected from the blood may reflect: 1) redistribution of leukocytes from one tissue to another, 2) stress-induced activation or suppression of cellular activity compared to the resting or pre-stress state. Based on this paradigm, a number of immune measurements were made from six blood samples collected from each subject in each of the six exercise training groups and four samples collected from subjects in a non-exercise training control group. The control group was included so that seasonal variations in immune function could be distinguished from changes induced by exercise training. In this report, the immune measurements will be described in four basic categories: 1) leukocyte complete blood count, 2) lymphocyte surface expression of phenotypic and functional proteins, 3) the lymphocyte proliferation response, and 4) cytokine production (Bioactive peptides produced by lymphocytes and monocytes that act as intercellular signal molecules to amplify, coordinate, or down regulate the immune response).

Leukocyte complete blood count (CBC). The total leukocyte count (WBC) and the proportions of WBC that fall into the three major classes of leukocytes were measured by one of two clinical research laboratories. Both laboratories used an automated hematology analyzer to determine WBC and either a manual or automated differential method to determine the relative proportions of granulocytes (primarily neutrophils), lymphocytes, and monocytes.

Lymphocyte surface expression of phenotypic and functional proteins. The specific proteins on the surface of lymphocytes are an indication of cell subtype and functional characteristics. Fluorescently conjugated monoclonal antibodies specific to proteins of interest were used to identify the proportions of cells with

the protein and, in some cases, the density of the protein. Miles et al. (1998) describes the procedures for this measurement in detail. Combinations of two monoclonal antibodies, each with a different fluorescent tag, were used to label several aliquots of whole blood from each sample collected. The monoclonal antibodies and the protein or lymphocyte subset recognized by each antibody used during the course of this investigation are listed in Table 2. Each aliquot was labeled for two different proteins. Thus, several aliquots were labeled so that each of the proteins could be measured in at least one aliquot. A given cell could be negative for both or positive for one or both of the two proteins. Labeled cells were analyzed for fluorescence using a flow cytometer (first year of the study, Coulter EPICS 753; 2nd and 3rd years, Coulter XL). Data from the flow cytometer indicated what proportion of lymphocytes were positive for one or both of the proteins measured in that aliquot. This proportion, in conjunction with the lymphocyte concentration of the CBC, was used to calculate the concentration of lymphocytes in the circulation bearing that protein.

Table 2. Monoclonal antibody designations and the protein or lymphocyte subset recognized.

Monoclonal designation	**Surface protein or lymphocyte subset recognized**
For setting analytic gates:	
CD45	Leukocyte common antigen, identifies all leukocytes
CD14	Monocytes, to exclude these cells from lymphocyte analysis (neutrophils excluded by size)
Subsets and proteins of interest:	
CD3	T cells (CD3+)
CD4	T helper cells (CD3+/CD4+)
CD8	T cytotoxic cells (CD3+/CD8+)
CD16 and CD56	Natural killer lymphocytes
CD19	B lymphocytes
CD45RA	Naïve T or B lymphocytes
CD45RO	Memory T or B lymphocytes
CD49d	VLA-4 integrin (an adhesion molecule)
CD62L	L-selecting (an adhesion molecule)
Attempted to measure but not successful:	
CD25	Interleukin-2 receptor (density insufficient to detect fluorescence)
CD69	Activated lymphocytes (analytical interference by platelets)

Lymphocyte proliferation response. To mount an effective secondary immune response to infection, the T and B lymphocytes must proliferate. The ability of T and B lymphocytes to proliferate can be assessed *in vitro* using a mitogen assay. Dohi et al. (MS in review) describes the procedures used to perform this assay. Briefly, peripheral blood mononuclear cells (PBMC) were isolated from whole blood and stimulated with phytohemagglutinin M (PHA), Concanavalin A (Con A), pokeweed mitogen (PWM), and staphylococcus *aurius cowans.* The first three are mitogens that stimulate proliferation directly; the latter is a super-antigen that elicits a

secondary proliferation response dependent on antigen presentation by monocytes in the culture. Cell cultures including PBMC and cell culture medium alone or medium plus mitogen or antigen (low and high concentrations of each done in replicates of six) were incubated for 70-74 h. A pulse of ^{3}H-thymidine was added during the final six hours of incubation. At the end of the assay, the DNA was collected on a glass filter mat using an automated cell harvester. Incorporation of the ^{3}H-thymidine into the DNA of the proliferating cells was used to quantitate cell proliferation for each of the cell culture conditions.

Cytokine production. The cytokines measured included interleukin (IL)-1β, IL-1 receptor antagonist (IL-1ra), and IL-6. Interleukin-1β is a pro-inflammatory mediator, IL-6 is a pivotal cytokine that has some pro-inflammatory functions, but it also induces the synthesis of several anti-inflammatory mediators, and IL-1ra is an anti-inflammatory mediator that blocks the activity of IL-1β. Lymphocytes and monocytes, collectively called mononuclear cells, were isolated from whole blood. Dohi et al. (in review) describes the density centrifugation procedure to isolate the PBMC. After isolation, PBMC were resuspended in cell culture medium at a concentration of 2×10^{6} cells·ml^{-1}. Phytohemagglutinin A (PHA), a plant lectin that stimulates cytokine production monocytes and lymphocytes and proliferation by T lymphocytes, was added to the cell culture medium (10 μl·ml^{-1}) before incubating at 37 °C and 5% CO_2. Culture supernatants were collected after 1, 3, 5, and 20 hours of PHA stimulation. The concentration of each cytokine was measured using a standard ELISA assay technique.

Exercise Training

Periodized Resistance Training. The four resistance training groups included total strength/power, upper strength/power, total hypertrophy, and upper hypertrophy. Subjects were supervised by a trainer (i.e., one on one) who prescribed the training loads used for each set, prepared the appropriate apparatus, spotted the subject, and monitored the rest periods. The training loads (kg) were determined relative to each subject's 1-RM capability and were closely monitored. Resistance was subtly increased in each exercise from one training session to the next according to the subject's capability, and was significantly increased concomitant with the reduction of repetitions from one mesocycle to the next. Specifically, training loads were increased when a subject was able to complete the required number of repetitions without deviation from safe and correct exercise technique. Training loads were increased in increments of 2.2, 4.5, 6.8, 9.1, 11.4, or 13.6 kg depending on the absolute load used (i.e., the greater the absolute training load, the larger the increment of increase). Exercises, number of repetitions, number of sets, and length of rest periods were preliminarily designed according to the specific training group and are shown in detail in the Tables 3-5 below.

Total (TP) and Upper Strength/Power (UP) Training. Total strength/power and UP programs consisted of identical training protocols but differing exercise designs. Both groups performed alternating sets of two exercises usually antagonistic in nature. Specifically, a set of one exercise (e.g., bench press) would, after the appropriate rest length, be followed by a set of the other exercise (e.g.,

seated row) until the appropriate number of sets of each exercise was completed (i.e., three). Rest time for both groups during all three mesocycles was two minutes between sets of alternating exercises such that four to five minutes occurred between sets of any one exercise (e.g., bench press). The repetitions ranged between three and eight per set, starting with eight more frequently in the first mesocycle and shifting towards five and then three throughout the next two mesocycles. Differentiation of design between the TP and UP programs was mostly the elimination of hip and leg exercises from the UP program. The TP program included rudimentary large muscle group exercises for the total body, while the UP program incorporated the same upper body exercises with additional supplementary upper body exercises in place of the hip and leg exercises. Both strength/power training groups performed their respective programs on three alternating days per week, followed by 20-25 minutes of aerobic endurance exercise in the training zone (i.e., training heart rate of 70 to 85% of maximal heart rate).

Total (TH) and Upper Hypertrophy (UH) Training. Total hypertrophy and UH programs also consisted of identical training protocols with differing exercise designs. The first and second, four-week mesocycles consisted primarily of 12 and 10 repetitions per set, respectively, 90 seconds rest between sets of large muscle group exercises (e.g., squat), 60 seconds between smaller muscle group exercises (e.g., dumbbell incline press), and 30 seconds between assistance exercises (e.g., upright row). The third four-week mesocycle consisted of 8 repetitions per set, 60 seconds rest between sets of large muscle group exercises, and 30 seconds between smaller muscle group and assistance exercises. Both hypertrophy training groups performed three consecutive sets of each resistance exercise with 90

second rests between different exercises during all three mesocycles. As with the TP and UP programs, the differentiation of design between the TH to UH programs was mostly the elimination of hip and leg exercises from the UH program. The TH program included rudimentary large muscle group exercises for the total body, while the UH program incorporated the same upper body exercises with additional supplementary upper body exercises in place of the hip and leg exercises. Both hypertrophy training groups performed their respective programs on three alternating days per week, followed by 20-25 minutes of aerobic endurance exercise in the training zone (i.e., training heart rate of 70 to 85% of maximal heart rate).

Differences between Strength/Power and Hypertrophy Training Programs. A differing style of approach for performing each repetition was taught to the strength/power versus hypertrophy training groups. The power training groups were specifically taught to accentuate (but not exaggerate) a stretch-contraction style of lifting, for a powerful completion of each repetition of each exercise. The subjects were told to "explode" on each repetition, regardless of how heavy the resistance or how fatigued the subject was. The hypertrophy training groups were specifically taught to slowly lower and slowly raise the resistance (without exaggeration) in order to attain a hyperemic or "pumped" state for all exercises during the training sessions. In regards to exercise choice, the primary difference among strength/power and hypertrophy training programs was the inclusion of two power exercises, the high pull and dumbbell (DB) power clean and press, into the TP program.

Field Calisthenics/Ballistic Plyometric Training. The FLD program consisted of a 24-week periodized training program divided into two 12-week macro-cycles, each consisting of a four-week mesocycle followed by an eight-week mesocycle. Subjects in the FLD group performed calisthenics (e.g., push-ups, sit-ups, self-squats, etc.), ballistic bounding plyometrics, manual resistance (i.e., exercises performed with towels where the partner would provide the resistance against which the subject pulled or pushed), and dumbbell exercises (i.e., two five pound dumbbells were used to simulate a ten pound weapon [e.g., M-16]) designed as a training regimen that could easily be implemented into an "in the field" U. S. Army scenario. Subject's trained in pairs under the supervision of one or two trainers who coordinated the workout activities for a group of eight subjects. The manual resistance exercises included upright row/triceps push-down, narrow pull-down/hammer curl, curl/triceps push-down and seated row each performed by pairs of subjects so that both were exercising simultaneously. For example, the upright row/triceps push-down exercises were combined into one activity for two subjects. Standing facing each other, one subject gripped the middle of a rolled towel with an overhand grip and performed an upright row by pulling upwards towards the chin using the deltoids. The other subject was simultaneously performing the triceps push-down against the resistance provided by the partner. By gripping the two ends of the towel with an overhand grip, the subject pushed down towards the floor with the upper arms held in place against the torso using the triceps. To incorporate a progressive component to this program, the number of repetitions were increased after the first four-week mesocycle for exercises where additional resistance could not be added (i.e., self-squat, lateral lunges, dumbbell good-morning, etc.). For manual resistance exercises, the number of repetitions were reduced after the first mesocycle and subjects were instructed

to increase the resistance applied. The FLD group performed their program on three alternating days per week, followed by 20-25 minutes of aerobic endurance exercise in the training zone (i.e., training heart rate of 70 to 85% of maximal heart rate).

Aerobic Endurance Exercise. The aerobic exercise in this study consisted of running, cycling, or stair-stepping. Subjects were permitted to choose a different mode of exercise, but were required to incorporate running at least once per week. In addition, to eliminate any confounding experimental treatment effects by having the AER group only do aerobics, we also provided them with a program of very light resistance band exercises (Jump Stretch, Boardman, Ohio) on three alternating days per week to complete their exercise period. This was thought to be essential so as to maintain compliance and allow the women to be feel they were not being "left out" of any programatic element when making causal comparisons with other groups. The AER training program consisted of a 24-week training program divided into two 12-week macro-cycles separated by 2 weeks of active rest. Subjects performed five minutes of warm-up exercises (i.e., jumping jacks, stretching, etc.), 25 to 35 minutes of aerobic exercise, and 10 minutes of light resistance band exercise shown in the exercise training Table 3. Heart rate values were monitored during aerobic endurance exercise (i.e., training heart rate of 70 to 85% of maximal heart rate). Subjects trained in groups of five under the supervision of one or two trainers who coordinated the workout activities. Aerobic exercise for the AER group included 35 minutes of group running twice per week and 25 minutes of either treadmill running, cycling, or stair-stepping once per week.

See Tables 3,4,and 5, which overview the training programs of the different experimental groups.

Table 3. Example one 12-week macrocycle of the total strength/power and upper strength/power periodized, heavy-resistance training programs.

Total Strength/Power

Monday (3 sets per exercise)	MSC 1 rep	MSC 1 m	MSC 2 rep	MSC 2 m	MSC 3 rep	MSC 3 m
Dumbbell Clean & Press	8 / 8	2	5 / 8	2	3 / 6	2
Dumbbell Incline Press	8		5		3	
Front Pull-Down	8	2	8	2	6	2
Squat	8		5		3	
Inclined Sit-Up	15	2	15	2	15	2
Upright Row	8		8		5	
Dumbbell Row	8	2	8	2	5	2

Wednesday (3 sets per exercise)	MSC 1 rep	MSC 1 m	MSC 2 rep	MSC 2 m	MSC 3 rep	MSC 3 m
High Pull	8		5		3	
Leg Curl	8	2	8	2	6	2
Bench Press	8		5		3	
Seated Row	8	2	5	2	5	2
Dumbbell Press	8		5		3	
Lat. Pull-Down	8	2	8	2	6	2
Calf Raise	8		8		8	
Abdominal Crunch	25	2	25	2	25	2

Friday (3 sets per exercise)	MSC 1 rep	MSC 1 m	MSC 2 rep	MSC 2 m	MSC 3 rep	MSC 3 m
High Pull	8		5		3	
Weighted Sit-Up	8	2	10	2	10	2
Squat	8		5		3	
Calf Raise	8	2	8	2	8	2
Narrow Bench Press	8		5		3	
Dumbbell Row	8	2	5	2	5	2
Leg Extension	8		8		6	
Leg Curl	8	2	8	2	6	2

Upper Strength/Power

Monday (3 sets per exercise)	MSC 1 rep	MSC 1 m	MSC 2 rep	MSC 2 m	MSC 3 rep	MSC 3 m
Bench Press	8		5		3	
Seated Row	8	2	5	2	5	2
Dumbbell Press	8		5		3	
Lat. Pull-Down	8	2	8	2	6	2
EZ Bar Biceps Curl	8		8		6	
Triceps Push-Down	8	2	8	2	6	2
Inclined Sit-Up	20		20		20	
Back Extension	8	2	10	2	8	2

Wednesday (3 sets per exercise)	MSC 1 rep	MSC 1 m	MSC 2 rep	MSC 2 m	MSC 3 rep	MSC 3 m
Dumbbell Incline Press	8		5		3	
Front Pull Down	8	2	8	2	6	2
Upright Row	8		5		5	
Dumbbell Row	8	2	5	2	5	2
Dumbbell Curl	8		8		6	
Dumbbell Triceps Ext.	8	2	8	2	6	2
Abdominal Crunch	25	1	25	1	25	1

Friday (3 sets per exercise)	MSC 1 rep	MSC 1 m	MSC 2 rep	MSC 2 m	MSC 3 rep	MSC 3 m
Bench Press	8		5		3	
Seated Row	8	2	5	2	5	2
Dumbbell Press	8		5		3	
Lat. Pull-Down	8	2	8	2	6	2
EZ Bar Biceps Curl	8		8		6	
Triceps Push-Down	8	2	8	2	6	2
Weighted Sit-Up	8		10		8	
Back Extension	8	2	10	2	8	2

Table 4. Example one 12-week macrocycle of the total hypertrophy and upper hypertrophy periodized, heavy-resistance training programs.

Total Hypertrophy

Monday (3 sets per exercise)	MSC 1		MSC 2		MSC 3	
	rep	s	rep	s	rep	s
Squat	12	90	10	90	8	60
Leg Extension	12	60	10	60	8	30
Leg Curl	12	60	10	60	8	30
Dumbbell Incline Press	12	60	10	60	8	60
Chest Fly	12	60	10	60	8	60
Front Pull-Down	12	60	10	60	8	60
Upright Row	12	30	10	30	8	30
Dumbbell Row	12	30	10	30	8	30
Rotational Ab. Crunch	25	60	25	60	25	60

Wednesday (3 sets per exercise)	MSC 1		MSC 2		MSC 3	
	rep	s	rep	s	rep	s
Leg Extension	12	90	10	90	8	30
Leg Curl	12	90	10	90	8	30
Calf Raise	12	60	10	60	8	30
Bench Press	12	90	10	90	8	60
Seated Row	12	90	10	90	8	60
Triceps Push-Down	12	30	10	30	8	30
EZ Bar Biceps Curl	12	30	10	30	8	30
Sit-Up	25	60	25	60	25	60

Friday (3 sets per exercise)	MSC 1		MSC 2		MSC 3	
	rep	s	rep	s	rep	s
Squat	12	90	10	90	8	60
Leg Curl	12	60	10	60	8	30
Calf Raise	12	60	10	60	8	30
Narrow Bench Press	12	90	10	90	8	60
Dumbbell Row	12	90	10	90	8	30
DB Triceps Extension	12	30	10	30	8	30
Dumbbell Curl	12	30	10	30	8	30
Abdominal Crunch	25	60	25	60	25	60

Upper Hypertrophy

Monday (3 sets per exercise)	MSC 1		MSC 2		MSC 3	
	rep	s	rep	s	rep	s
Bench Press	12	90	10	90	8	60
Seated Row	12	90	10	90	8	60
Dumbbell Press	12	60	10	60	8	60
Lat. Pull-Down	12	60	10	60	8	60
EZ Bar Biceps Curl	12	30	10	30	8	30
Triceps Push-Down	12	30	10	30	8	30
Rotational Ab. Crunch	25	60	25	60	30	30
Back Extension	12	60	10	60	8	30

Wednesday (3 sets per exercise)	MSC 1		MSC 2		MSC 3	
	rep	s	rep	s	rep	s
Dumbell Incline Press	12	90	10	90	8	60
Front Pull Down	12	90	10	90	8	60
Upright Row	12	60	10	60	8	60
Dumbbell Row	12	60	10	60	8	60
Dumbbell Curl	12	30	10	30	8	30
DB Triceps Extension	12	30	10	30	8	30
Sit-Up	25	60	25	60	30	60

Friday (3 sets per exercise)	MSC 1		MSC 2		MSC 3	
	rep	s	rep	s	rep	s
Bench Press	12	90	10	90	8	60
Seated Row	12	90	10	90	8	60
Dumbbell Press	12	60	10	60	8	60
Lat. Pull-Down	12	60	10	60	8	60
EZ Bar Biceps Curl	12	30	10	30	8	30
Triceps Push-Down	12	30	10	30	8	30
Rotational Ab. Crunch	25	60	25	60	30	30
Back Extension	12	60	10	60	8	30

MSC = mesocycle, rep = repetitions, s = seconds, Ab = Abdominal, DB = Dumbbell, Lat = Latissimus

Table 5. Example one 12-week macrocycle of the field and aerobic training programs.

Field

Monday (3 sets per exercise)	MSC 1 rep	MSC 1 s	MSC 2 (8 wk) rep	MSC 2 (8 wk) s
Self-Squat	20	60	25	60
Lateral Lunges	12	60	14	60
DB Goodmorning	12	60	14	60
Wide Push-Ups	12	60	10	60
Upright Row/ Tri. Push-Down (MR)	12	60	10	60
Narrow Pull-Down/ Hammer Curl (MR)	12	60	10	60
Sit-Up	25	60	25	60

Wednesday (3 sets per exercise)	MSC 1 rep	MSC 1 s	MSC 2 (8 wk) rep	MSC 2 (8 wk) s
Isometric Wall Squat	20s	60	30s	60
DB Goodmoring	12	60	15	60
Self-Heel Raise	20	60	25	60
Push-Ups	12	60	10	60
Seated Row (MR)	12	60	10	60
Biceps Curl/ Tri. Push-Down (MR)	12	60	10	60
Sit-Up	25	60	25	60

Friday (3 sets per exercise)	MSC 1 rep	MSC 1 s	MSC 2 (8 wk) rep	MSC 2 (8 wk) s
1 Leg Plyo- Bounds	6	60	8	60
2 Leg Plyo- Bounds	6	60	8	60
Lunges	12	60	14	60
Narrow Push-Ups	12	60	10	60
Seated Row (MR)	12	60	10	60
One Arm DB Curl	12	60	14	60
Abdominal Crunch	25	60	25	60

Aerobic/Light Resistance Band

Monday	
Stretching and Shoulder, Arm, Ankle, and Neck Circles	20 second duration each
Jumping Jacks	20 second duration
Group Running	35 minutes, HR 144-156
Quarter ROM Squats ***Chest Squeeze (RB)*** ***Tri. Ext. Squeeze (RB)*** Spine Erector Squeeze Abdominal Crunch	3 circuits of 10 repetitions per exercise with 1 minute rests between circuits

Wednesday	
Stretching and Shoulder, Arm, Ankle, and Neck Circles	20 second duration each
Jumping Jacks	20 second duration
Aerobic Exercise	25 minutes, HR 144-156
Quarter ROM Squats Pull-Down Sqz (RB) Row Squeeze (RB) Rear Deltoid Sqz (RB) Biceps Curl Sqz (RB)	3 circuits of 10 repetitions per exercise with 1 minute rests between circuits

Friday	
Stretching and Shoulder, Arm, Ankle, and Neck Circles	20 second duration
Jumping Jacks	20 second duration each
Group Running	35 minutes, HR 144-156
1/4 ROM Wide Squats	

MSC = mesocycle, rep = repetitions, s = seconds, DB = Dumbbell, RB = resistance band exercises, Tri = triceps MR = manual resistance exercises, Sqz = squeeze, Plyo = plyometric exercises

Statistical Analyses

Tabular data are presented as the mean ± SE. Tests for statistical assumptions were performed (e.g., normality, sphericity). Repeated measures MANOVA was used to test main effects of training (0, 3, and 6 months), time (pre- and post- exercise for the 6x10 RM squat exercise). In addition, the men's group was put into the analysis of various variables related to physical performance. When a significant F-ratio was achieved, the Fisher LSD post-hoc test was used to determine where significant differences occurred. Regression analyses were used for determining selected bi-variate relationships. Test-retest reliability correlation (intra-class R's) for all performance tests were ≥ 0.95. Statistical power ranged from 0.80 to 0.98 at a P-value equal to 0.05 for the n sizes used in the study. Significance in this study was defined as $p \leq 0.05$.

RESULTS AND DISCUSSION

Muscle Cross-Sectional Areas of Thigh and Arm Musculature

Mid-Upper Thigh. No differences were observed among groups in mid-thigh muscle cross-sectional area at T1 (Table 6). Significant interaction occurred between the TP, UP, TH, and UH groups in mid-thigh muscle cross-sectional area during training. Mid-thigh muscle cross-sectional area increased significantly from T1 to T2 and T1 to T3 in the TP and TH groups. Differences among groups in mid-thigh muscle cross-sectional area at T2 included greater area in the TP and TH groups as compared to the UP and UH groups. The TP and TH groups exhibited hypertrophy of the thigh from T1 to T2 (~3.3%) and from T2 to T3 (~4.4%), whereas the UP and UH groups showed small, but significant gains from T2 to T3 only. At T3, mid-thigh muscle cross-sectional area was greater in the TP and TH groups as compared to the UP and UH groups. Other differences among groups at T3 included greater mid-thigh muscle cross-sectional area in the UH group than the UP group.

Mid-Upper Arm. No differences were observed among groups in mid-upper arm muscle cross-sectional area at T1, T2, or T3 (Table 6). Group x time interaction between the TP, UP, TH, and UH groups for mid-upper arm muscle cross-sectional area was not significant. Mid-upper arm muscle cross-sectional area increased significantly from T1 to T2 and T1 to T3 in the TP, UP, TH, and UH groups. These changes represented ~11% increase from T1 to T2 and a further ~6% increase

from T2 to T3. In general the degree of hypertrophy was higher in the arms when compared to the thigh for each group.

Table 6. Mean ± SD for magnetic resonance imaging assessed thigh and arm muscle cross-sectional areas (cm^2) for the TP, UP, TH, and UH training groups before (T1), following 3 months (T2), and 6 months of training (T3).

Group	T1	T2	T3
Total Power			
TCSA	123.0 ± 15.8	128.4 ± 16.3*	134.3 ± 16.1*#
ACSA	33.2 ± 4.2	35.2 ± 4.1*	37.5 ± 4.5*#
Upper Power			
TCSA	122.3 ± 17.5	120.1 ± 17.9t	123.6 ± 15.0t
ACSA	32.0 ± 3.8	35.7 ± 4.7*	38.4 ± 4.4*#
Total Hypertrophy			
TCSA	124.7 ± 15.7	127.5 ± 12.6*	132.9 ± 14.5*#
ACSA	31.9 ± 6.1	36.1 ± 4.5*	37.6 ± 5.0*#
Upper Hypertrophy			
TCSA	123.4 ± 17.4	121.7 ± 16.7t	127.1 ± 16.3t
ACSA	32.3 ± 5.3	36.6 ± 5.8*	38.5 ± 7.5*#

* $P < 0.05$ vs. corresponding T-1 value # = $P < 0.05$ vs. corresponding T-2 value, t=$P < 0.05$ vs. corresponding Total Power and Total Hypertrophy values, p = $P < 0.05$ vs. corresponding Upper Power value

A sedentary control group (n=10) demonstrated intra-class reliability correlations of $R \geq 0.98$ on all experimental measures over the time period tested.

The periodized heavy resistance training model employed in this study proved effective for eliciting hypertrophic adaptations in upper and lower body musculature in previously untrained women. No plateau (i.e. no significant change over time) was observed in the training paradigm as significant increases in sizes of muscle tissue were apparent during the latter half of the study (T2 to T3) in all of

the groups that trained the musculature. While neural factors are thought to make the major contribution to strength and power gains early in a program, an increasing awareness is recognized concerning adaptations intrinsic to muscle tissue. These data support a much more rapid early phase of development of the intact muscle hypertrophy than has been previously shown (Cureton et. al, 1988). Muscle tissue can enhance strength and power capabilities by several means including alteration of the proportion of contractile/non-contractile proteins, myofibrillar isoform modifications, and muscle fiber and tissue hypertrophy (Fleck and Kraemer, 1997; Staron et al., 1991;1994).

Interestingly, there was no correlation between hypertrophy between the arms and legs in the training groups. This indicates that the pattern of hypertropy between the two parts of the body may be different. The higher magnitude of hypertrophy seen in arms of the upper body groups may be due to the fact that the reduction in the amount of muscle tissue trained in the upper body groups allowed for greater amounts of nitrogen retention in that area over time as has been seen in older populations (Kraemer, Fleck, and Evans, 1996). The quick hypertophic responses of the thigh and the arms to resistance be due to an inherent lack of resistance activities in the women prior to the study (Wilmore, 1974).

Physical Performance Measures

1-RM Bench Press. No differences were observed among groups in 1-RM bench press at T1 (Figure 1). Significant interaction occurred between groups in 1-RM

bench press during training. One-RM bench press increased significantly from T1 to T2 in the TP and UP groups. Differences among groups in 1-RM bench press at T2 included greater performance in the TP, UP, TH, and UH groups than the AER group. Also at T2, 1-RM bench press was heavier in the TP, UP, and UH groups than the FLD group. One-RM bench press increased significantly from T1 to T3 in all training groups except the AER group. The training (i.e., time) effect in 1-RM bench press in all the groups except the AER from T2 to T3 was significant. Differences among groups in 1-RM bench press at T3 included greater performance in the TP group as compared to the TH, FLD, and AER groups. Also at T3, 1-RM bench press was heavier in the UP and UH groups than the FLD and AER groups; and in the TH group as compared to the AER group. Delta changes in 1-RM bench press from T1 to T3 were significantly greater in the TP (12.1 ± 4.9 kg), UP (10.0 ± 3.9 kg), TH (8.5 ± 5.7 kg), UH (9.4 ± 6.0 kg), and FLD groups (9.3 ± 2.5 kg) than the AER group (1.7 ± 3.1 kg). The 1-RM bench press in the MEN group (81.0 ± 19.7 kg) was significantly heavier than all women's groups at all experimental testing sessions (heaviest women's value = 47.5 ± 8.5 kg in the TP group at T3).

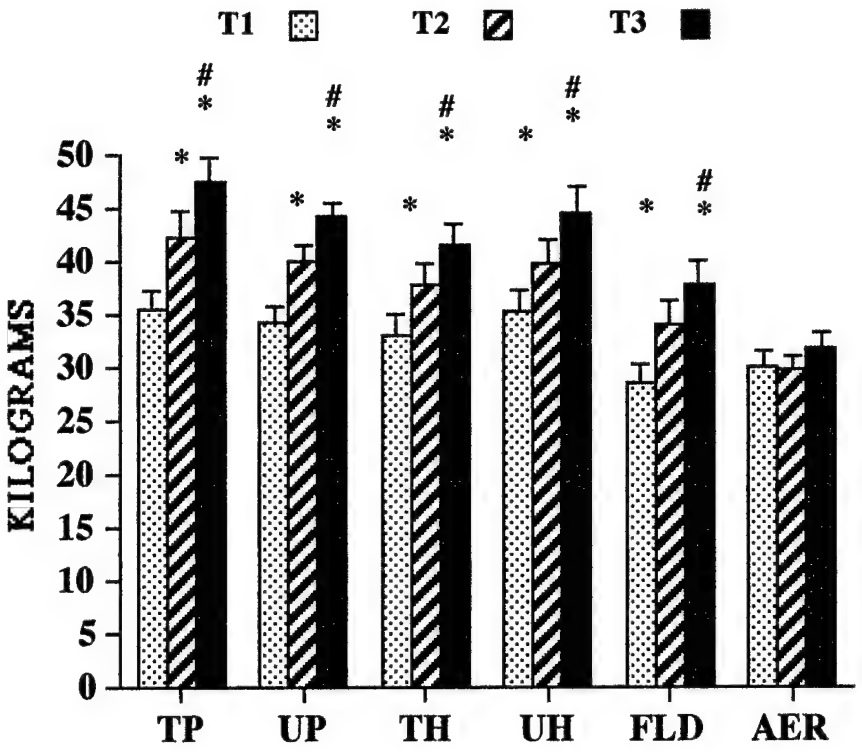


Figure 1. Comparison of 1-RM bench press performance (kg) at Baseline (T1) and following 3 (T2) and 6 months (T3) of total strength/power (TP), upper strength/power (UP), total hypertrophy (TH), upper hypertrophy (UH), field/ballistic plyometric (FLD), or aerobic/light resistance band training (AER). * $P < 0.05$ vs. corresponding T1 value. # $P < 0.05$ vs. corresponding T2 value. Values are means ± SE.

The programs increased upper body strength for all groups as might be expected although the magnitude of gains in the second three months of training remained a lower in magnitude. This may reflect the lower amount of gains also seen in the muscle size of the arm reported above. The field group while making significant increases using various weight exercises for the chest (e.g., partner push ups) the magnitude of gain was lower than the in-weight room response. However, such a program may be helpful in maintaining strength gains in the field. Based on specificity alone and despite using a light rubber band placebo program, the aerobic training group did not make any gains in their upper body maximal force

development (Fleck and Kraemer, 1997). The changes in the bench press strength reflected the adaptations in the arm musculature which were probably reflective of the other muscles activated in the upper body with chest training.

1 RM Squat. *1-RM Squat.* Differences among groups in 1-RM squat at T1 included greater performance in TP, UP, and TH groups and all of the resistance training groups as compared to the FLD and AER groups, respectively (Figure 2). Significant interaction occurred between groups in 1-RM squat during training. One-RM squat increased significantly from T1 to T2 in the TP and TH groups. Differences among groups in 1-RM squat at T2 included greater performance in the TP group than the FLD and AER groups. Also at T2, 1-RM squat was heavier in the TH group than the AER group. . One-RM squat increased significantly from T2 to T3 in the TP and TH groups. One-RM squat increased significantly from T1 to T3 in the TP, TH, and FLD groups. Differences among groups in 1-RM squat at T3 included greater performance in the TP and TH groups than the UP, UH, FLD, and AER groups. Delta changes in 1-RM squat from T1 to T3 were significantly greater in the TP (20.1 ± 6.4 kg) and TH groups (18.4 ± 11.9 kg) than the UP (4.3 ± 7.7 kg) and UH groups (7.5 ± 6.3 kg). Delta changes were 14.1 ± 8.3 and 11.4 ± 11.8 kg in the FLD and AER groups, respectively. The 1-RM squat in the MEN group (100.6 ± 24.5 kg) was significantly heavier than all women's groups at all experimental testing sessions (heaviest value = 73.0 ± 10.3 kg in the TP group at T3). The 1-RM squat relative to fat-free mass (1-RM squat (kg)/FFM (kg)), however, was not significantly different between the TP (1.49 ± 0.18), TH (1.44 ± 0.29), and MEN groups (1.54 ± 0.36) following 6 months of training.

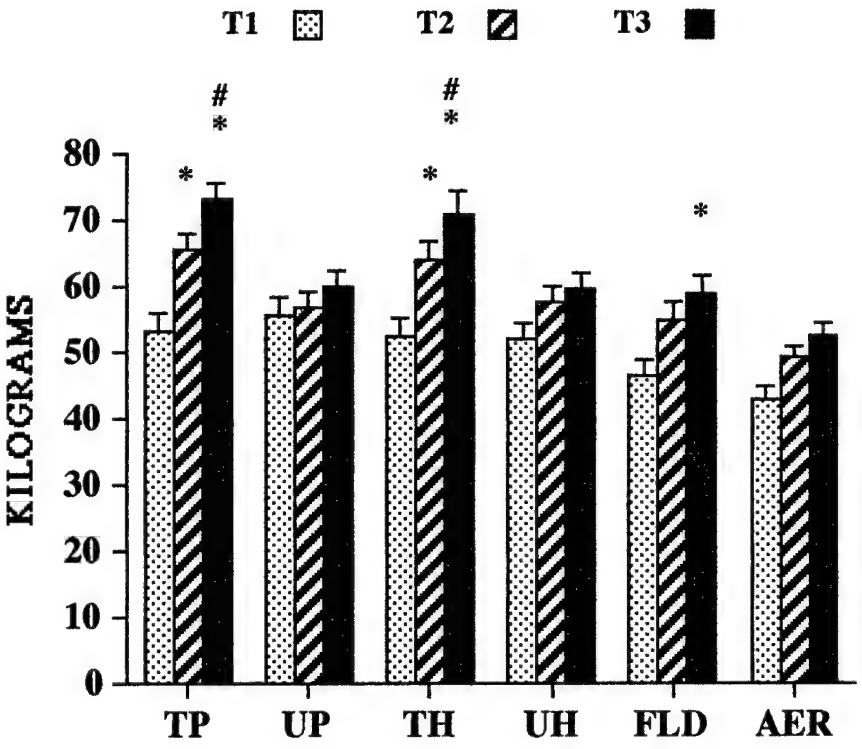


Figure 2. Comparison of 1-RM squat performance (kg) at Baseline (T1) and following 3 (T2) and 6 months (T3) of total strength/power (TP), upper strength/power (UP), total hypertrophy (TH), upper hypertrophy (UH), field/ballistic plyometric (FLD), or aerobic/light resistance band training (AER). * $P < 0.05$ vs. corresponding T1 value. # $P < 0.05$ vs. corresponding T2 value. Values are means ± SE.

The changes in the 1 RM squat reflected the principle of "specificity" of training in that only those groups that squat trained the lower body musculature demonstrated increases in the 1 RM. Again the field group did do self squats but these data demonstrate that an aggressive explosive plyometric program that also

uses the squat movement influences the gains in muscle force production (Häkkinen et al., 1990; 1993; Fleck and Kraemer, 1997). However, the magnitude of gain was much lower in this group due to a lack of significant loading and shows most likely the amount of influence a plyometric power program can have. Here again, such a program of self-squats and aggressive plyometric jump training may be helpful in maintaining strength gains in the field where equipment is not readily available.

1-RM High Pull. Differences among groups in 1-RM high pull at T1 included greater performance in the TP, UP, TH, and UH groups as compared to the AER group (Figure 3). One-RM high pull performance also was significantly greater in the TP, UP, and UH groups than the FLD group at T1. Significant interaction occurred between groups in 1-RM high pull during training. One-RM high pull increased significantly from T1 to T2 and T1 to T3 in the TP group. One-RM high pull was heavier in the TP group than all other training groups at T2. Other differences among groups in the high pull at T2 included greater performance in the UP and TH groups than the AER group. At T3, 1-RM high pull was significantly greater in the TP group than all other training groups. Delta change in 1-RM high pull from T1 to T3 was significantly greater in the TP group (7.6 ± 3.5 kg) than the UP (2.2 ± 3.1 kg), TH (2.9 ± 4.4 kg), and UH groups (1.6 ± 3.4 kg). The 1-RM high pull in the MEN group (58.8 ± 9.6 kg) was significantly heavier than all women's groups at all experimental testing sessions (heaviest women's value = 41.0 ± 6.2 kg in the TP group at T3).

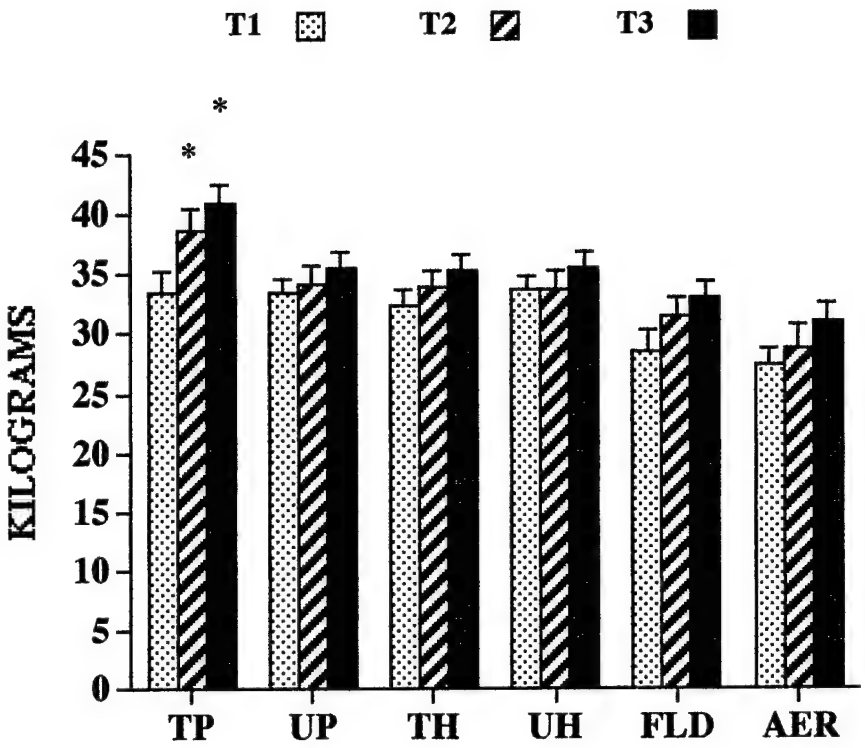


Figure 3. Comparison of 1-RM high pull performance (kg) at Baseline (T1) and following 3 (T2) and 6 months (T3) of total strength/power (TP), upper strength/power (UP), total hypertrophy (TH), upper hypertrophy (UH), field/ballistic plyometric (FLD), or aerobic/light resistance band training (AER). * $P < 0.05$ vs. corresponding T1 value. Values are means ± SE.

These results demonstrate that power development in women is very program specific. The TH group lifted with slower and less explosive movements than did the TP group. Even with the FLD group doing plyometric training, the loading was not enough to show improvements in power at this high loading task. In men this has been seen to also be the case (Kraemer 1997; Newton et al., 1999). Thus, when maximal power development at 1 RM loads are of concern, only explosive types of programs using heavy loading cycles (i.e., < 8 RM loads) can be used to improve this very important performance in physical abilities in men or women.

There was a clear separation from the squat and bench press 1 RM results from the high pull. This was surprising in that we thought a force component in the legs would contribute in the TH to improvements. It may show that specificity of exercise, technique practice, and limited transfer of slowly trained squat force to higher velocity and power movements could account for the differences. These data do show that there is a need for specialized training military skills that are different from normative exercise movements in technique. In addition, these data demonstrate that the force component of the lower body and upper body trained musculature in general do not transfer to a very specific whole body explosive power exercise. The choice of exercise is vital as well as the velocity of the exercise training to improve this specific type of exercise movement.

Squat Jump Power. No differences were observed among groups in the peak squat jump power output at 30, 60, or 90% of the 1-RM squat at T1 (Figures 4 to 6). Significant interaction occurred between groups in 30% peak power during training. Thirty % peak power increased significantly from T1 to T3 in the TP, TH and FLD groups. No differences were observed among groups in 30% peak power at T2 or T3. Delta change in 30% peak power from T1 to T3 was significantly greater in the TP group (310.2 ± 236.0 W) than the UP group (51.7 ± 200.8 W).

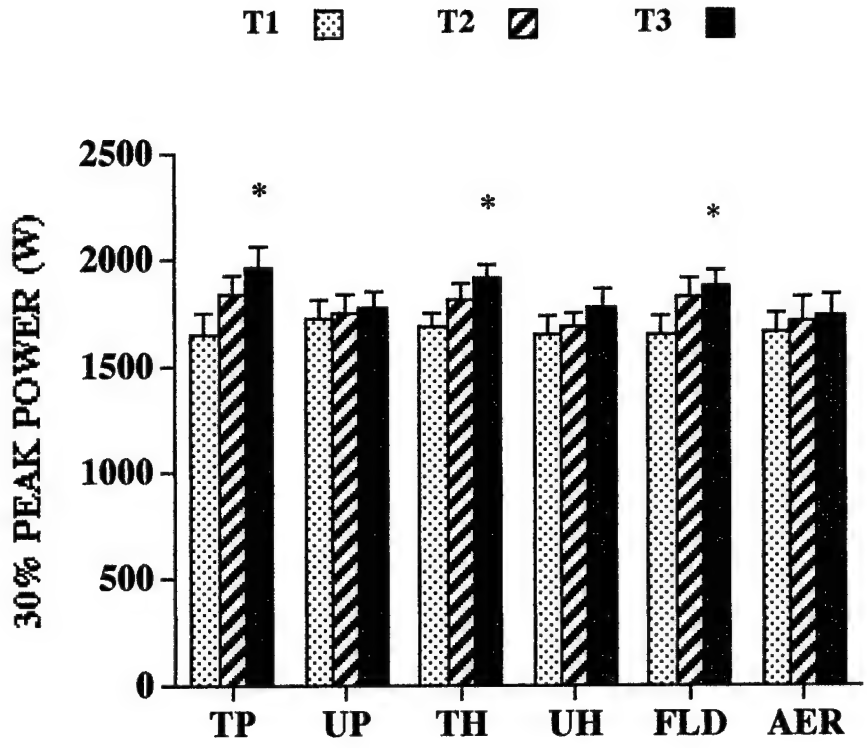


Figure 4. Comparison of 30% peak power output (W) at Baseline (T1) and following 3 (T2) and 6 months (T3) of total strength/power (TP), upper strength/power (UP), total hypertrophy (TH), upper hypertrophy (UH), field/ballistic plyometric (FLD), or aerobic/light resistance band training (AER). * $P < 0.05$ vs. corresponding T1 value. Values are means ± SE.

60% Squat Jump. Significant interaction occurred between groups in 60% peak power during training. Sixty % peak power increased significantly from T1 to T3 in the TP, TH and FLD groups. No differences were observed among groups in 60% peak power at T2 or T3. Delta changes in 60% peak power from T1 to T3 were significantly greater in the TP (230.0 ± 148.6 W), TH (251.8 ± 227.3 W), and FLD groups (232.2 ± 184.1 W) as compared to the UP group (-30.6 ± 172.4 W).

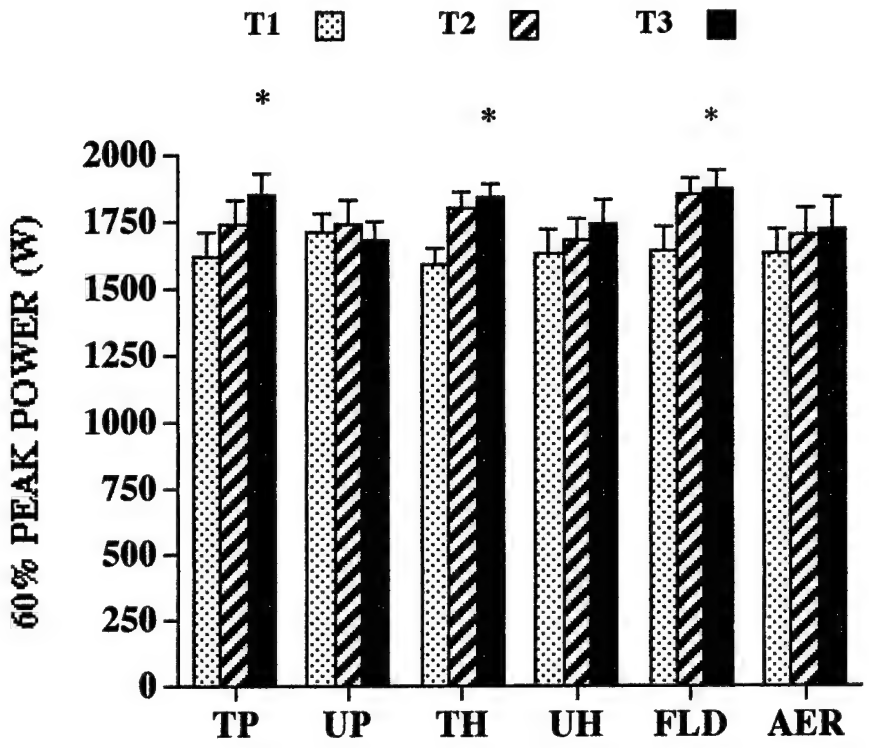


Figure 5. Comparison of 60% peak power output (W) at Baseline (T1) and following 3 (T2) and 6 months (T3) of total strength/power (TP), upper strength/power (UP), total hypertrophy (TH), upper hypertrophy (UH), field/ballistic plyometric (FLD), or aerobic/light resistance band training (AER). * $P < 0.05$ vs. corresponding T1 value. Values are means ± S

90% Squat Jump. Significant interaction occurred between groups in 90% peak power during training. Ninety % peak power increased significantly from T1 to T3 in the TP, TH, and FLD groups. Ninety % peak power was greater in the FLD group than the UP group at T3. The TP group also increased from T1 to T2. Delta changes in 90% peak power from T1 to T3 were significantly greater in the TP (228.3 ± 256.2 W), TH (142.3 ± 203.5 W), and FLD groups (276.6 ± 184.4 W) than the UP group (-89.8 ± 182.2 W).

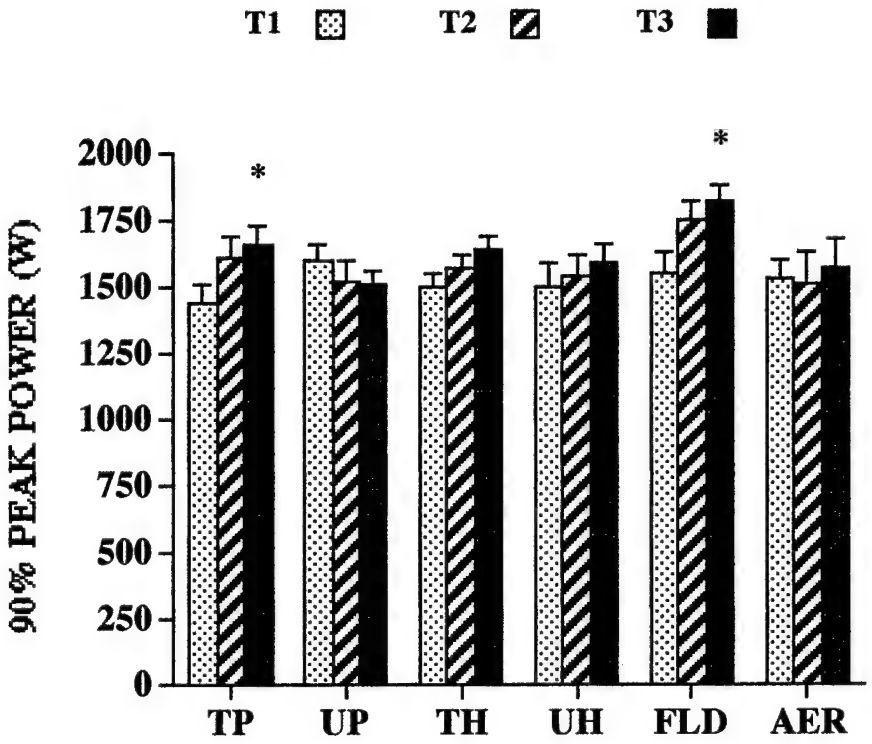


Figure 6. Comparison of 90% peak power output (W) at Baseline (T1) and following 3 (T2) and 6 months (T3) of total strength/power (TP), upper strength/power (UP), total hypertrophy (TH), upper hypertrophy (UH), field/ballistic plyometric (FLD), or aerobic/light resistance band training (AER). * $P < 0.05$ vs. corresponding T1 value. Values are means ± SE.

The results of the squat jump testing demonstrated that total body power movements (TP), adequate loading (TH) and plyometric training (FLD) were each effective in increasing loaded power movements in the squat. While the mechanisms which mediate such changes are probably a combination of neurological and/or muscle tissue increases in the lower body musculature, these data show that the upper body has little to do with enhancing this lower body power

generation. Nevertheless, the quickest and the greatest gains were made in the TP group where exercise movements were loaded at all ranges and explosive movements were utilized. The increases observed at T2 continued to increase to T3 but separation of the time points did not occur at 6 months of training indicating a need for longer training periods to affect these power variables. The slowing of the performance increases over the second phase of training may be expected either due to the closure on upper limits of adaptation or the need for a long period of training to make the same gains as the window of adaptation gets smaller (Fleck and Kraemer, 1997). This appears to be a concept especially related to power development which may be more complex. It is interesting to speculate what might have occurred if both TP and FLD group training characteristics (i.e, loading and plyometrics) were combined. Interestingly, the aggressive plyometric training program using "stretch shortening cycle" exercises was effective in providing gains in these movements without significant high force loading as seen in the TP group. It has been recently shown that signidicant hypertrophy is possible with 8 weeks of plyometric training in men (Potteiger et al., 1999) and such changes may help to mediate force production at all squat jump loads.

Bench Press Throw Power. No differences were observed among groups in the peak bench press throw power output (BT peak power) at T1 (Figure 7). Significant interaction occurred between groups in BT peak power during training. No significant training effects for BT peak power were observed from T1 to T2 except in the TP group. Bench throw peak power was greater in the TP group than the FLD and AER groups at T2. Other differences among groups in BT peak power at T2 included greater performance in the UP and UH groups as compared to the AER group. Bench throw peak power increased significantly from T1 to T3 in all

training groups except the AER group. Bench throw peak power was greater in the TP group than the FLD and AER groups at T3. Also at T3, BT peak power was greater in the UP and UH groups as compared to the AER group. Delta change in BT peak power from T1 to T3 was greatest in the TP group (67.6 ± 40.1 W), however, no differences were observed in the delta changes among any groups.

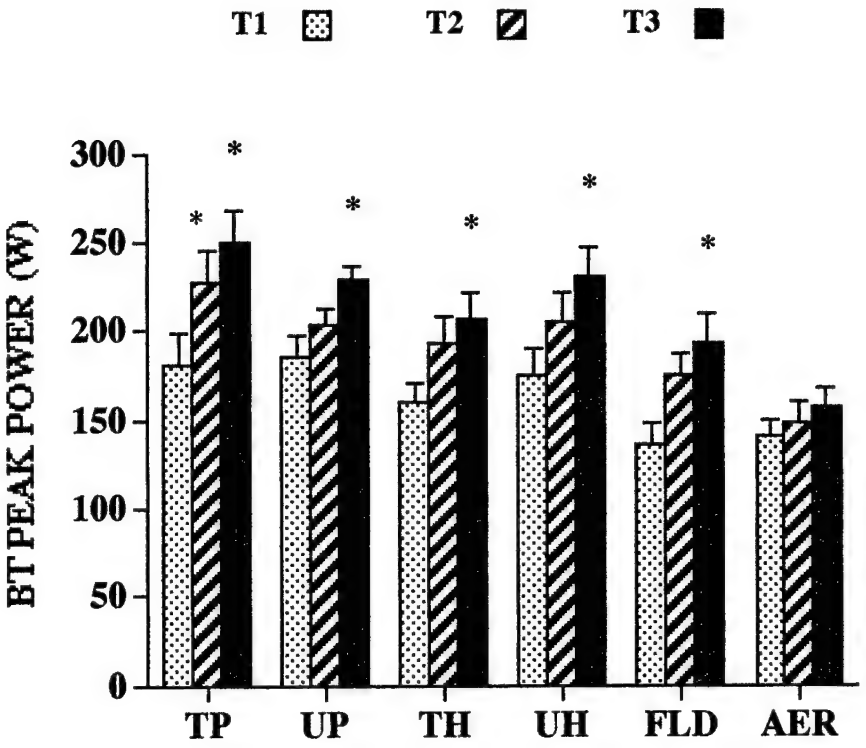


Figure 7. Comparison of bench press throw peak power output (W) at Baseline (T1) and following 3 (T2) and 6 months (T3) of total strength/power (TP), upper strength/power (UP), total hypertrophy (TH), upper hypertrophy (UH), field/ballistic plyometric (FLD), or aerobic/light resistance band training (AER). * $P < 0.05$ vs. corresponding T1 value, Values are means ± SE.

All of the groups except for the AER group demonstrated increases in the bench throw indicting that power development was again specific to the trained musculature and was also sensitive to an aggressive upper body plyometric training program which also included resistance loading. The changes mirrored the 1 RM bench press results except for the fact that power again lagged behind 1 RM strength changes in its rate of improvement, except for the TP group. This may be due to the lack of both the force and time components of the power equation being

addressed in the program (Newton et al., 1999). It might be speculated that increases in this test were due to increases in a combination of both increases in muscle size and/or neurological recruitment capabilities. Again, as in the squat jumps the TP group made the quickest and greatest gain in this power measure. Such data indicates that periodized training using the loading zones of 8 RM and under and explosive total body exercise movements are most effective in creating power enhancement in women. It appears that upper body power movement is sensitive to several mechanisms of adaptation as all of the training groups, except for the AER group, observed increases over the six month training period. The loading and exercise type used in the TP group was most effective! This has been shown in men in prior work (Kraemer, 1997; Newton et al., 1999).

Squat Endurance. No differences were observed among groups in squat endurance performance at T1 (Figure 8). Significant interaction occurred between groups in squat endurance performance during training. Squat endurance performance increased significantly from T1 to T2 in the TP and TH groups. Differences among groups in squat endurance at T2 included greater performance in the TH group than the UP, FLD, and AER groups. The TH group also made a significant improvement from T2 to T3 in the exercise movement. The TP and TH groups showed significant increases at T2. Squat endurance performance also was greater in the TP group than the UP and AER groups at T2. Squat endurance performance increased significantly from T1 to T3 in the TP, TH, and FLD groups. Squat endurance performance was greater in the TH group than the UP, UH, FLD, and AER groups at T3. Other differences among groups in the squat endurance at T3 included greater performance in the TP group than the UP, FLD and AER groups. Delta changes in squat endurance performance from T1 to T3 were greater

in the TP group (20.8 ± 11.0 reps) than the UP (8.8 ± 7.2 reps) and UH groups (9.1 ± 9.7 reps). Delta changes also were greater in the TH group (19.9 ± 11.0 reps) than the UP group. The squat endurance performance in the MEN group (59.5 ± 24.3 reps) was significantly greater than all women's groups at all experimental testing sessions (highest women's value = 44.4 ± 17.0 reps in the TH group at T3).

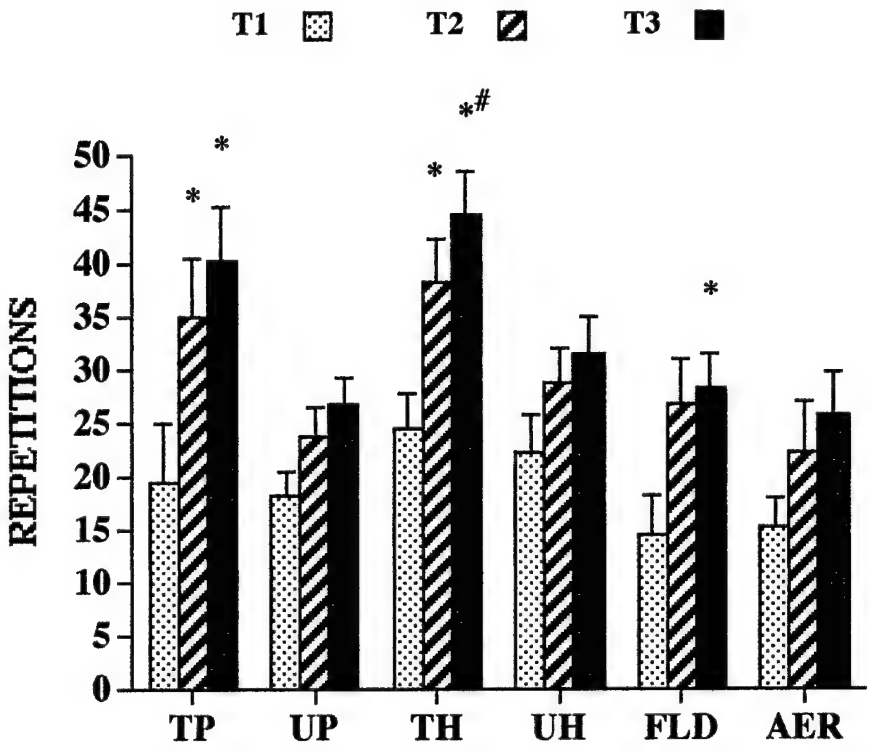


Figure 8. Comparison of squat endurance performance (reps) at Baseline (T1) and following 3 (T2) and 6 months (T3) of total strength/power (TP), upper strength/power (UP), total hypertrophy (TH), upper hypertrophy (UH), field/ballistic plyometric (FLD), or aerobic/light resistance band training (AER). * $P < 0.05$ vs. corresponding T1 value. # $P < 0.05$ vs. corresponding T2 value. Values are means ± SE.

The improvement in the squat endurance appears to be related to the total volume of exercise done and could also include aerobic development from the endurance training program part of the total conditioning program. All groups who did not increase in the exercise test showed a trend (P values from 0.09 to 0.10) toward significant improvements, even the AER group, however a significant P values were not observed. Thus, the endurance training effects may be seen in

this aspect of the program yet due to limited lower body loading significance as a grou(s) a signficant P value was not observed. Interestingly the TH group demonstrated continued development of this squat endurance capability over the training period different from the changes in their power measures. This was also the case in the FLD group who performed a higher number of high rep explosive exercise sets than of the other groups. A trend for this same effect was seen in the TP group but just missed significance (P = 0.09). It might be speculated that the consecutive increases in this variable in the TH group was due to the higher amounts of repetitions used in the training program (i.e., periodized over 12 to 8 repetitions and repeated with more high rep expoure). In the TP group the reduction of reps well below 8 may have limited development of this performance capability at the end of each training cycle thereby making gains in this capability difficult at best.

U. S. Army Physical Fitness Test

This set of tests were used as they are the most common battery of tests used in the U.S. Army to evaluate fitness. In general all training programs which in part address a muscular or cardiovascular component impact these tests and it does not appear that they are sensitive to subtle changes in a resistance training program itself.

Push-Ups. No differences were observed among groups in push-up performance at T1 (Figure 9). Significant interaction occurred between groups in push-up performance during training. Push-up performance increased significantly from T1 to T3 in the TP, UP, TH, UH and FLD groups. Differences among groups in push-

ups at T3 included greater performance in the UP group than the FLD and AER groups. Also at T3, push-up performance was greater in the TP, TH, and UH groups than the AER group. Delta changes in push-up performance from T1 to T3 were significantly greater in the UP (17.3 ± 10.1 reps), TH (15.3 ± 9.2 reps), and UH groups (18.0 ± 6.6 reps) than the AER group (3.1 ± 7.9 reps). Push-up performance in the MEN group (49.2 ± 16.0 reps) was significantly greater than all women's groups at all experimental testing sessions except the UP group at T3 (43.0 ± 10.5 reps).

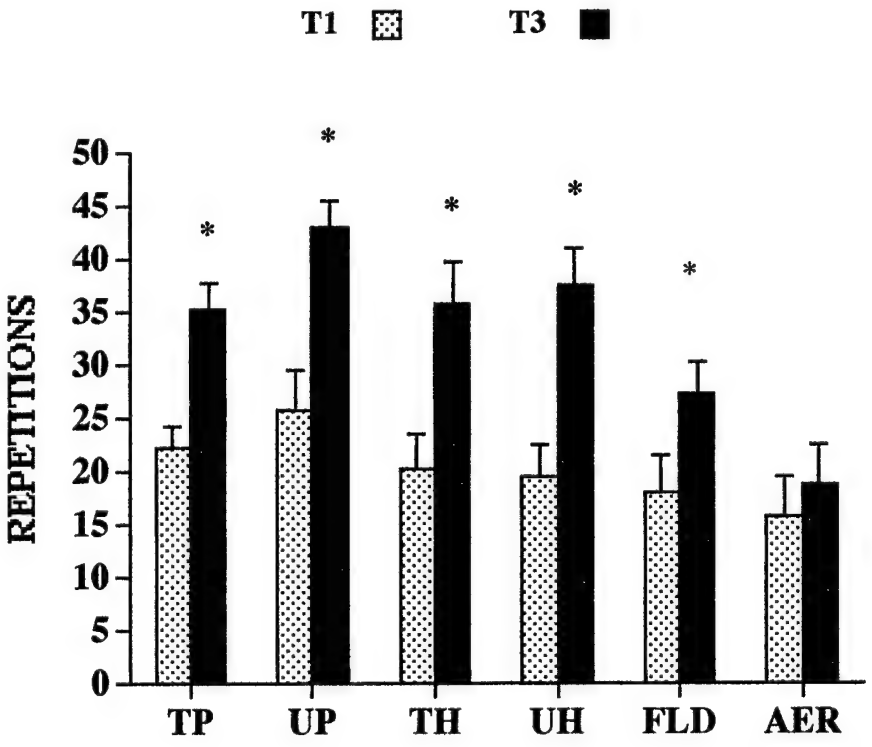


Figure 9. Comparison of push-up performance (reps) at Baseline (T1) and following 6 months (T3) of total strength/power (TP), upper strength/power (UP), total hypertrophy (TH), upper hypertrophy (UH), field/ballistic plyometric (FLD), or aerobic/light resistance band training (AER). * $P < 0.05$ vs. corresponding T1 value. Values are means ± SE.

The greatest gains were made in the resistance training groups and appears to be due to the use of loaded arm and chest exericses. The FLD group did resistive push ups but did not make the same magnitude of gains as did the other groups using weights. The AER group made no chaanges in this measure as might be expected without the use push ups in their training program. The light band exercises used by the AER group did not transfer any enhanced capabilities to this test. As has been observed in men, overload training of the upper body enhances this push up test movement (Kraemer et al., 1987). However, program differences are not readily observed between the resistance training groups. Only the UP group equaled the men in the average number of push ups performed but all groups made significant gains on the percentage of this study's normative value for men (i.e., 49.2 push-ups for men).

Sit-Ups. No differences were observed among groups in sit-up performance at T1 (Figure 10). Significant interaction occurred between groups in sit-up performance during training. Sit-up performance increased significantly from T1 to T3 in all training groups except the AER group. Differences among groups in sit-ups at T3 included greater performance in the TP and UP groups as compared to the FLD and AER groups. Sit-up performance also was greater in the TH, UH, and FLD groups than the AER group at T3. Delta changes in sit-up performance from T1 to T3 were significantly greater in the TP (25.3 ± 10.9 reps) and UH groups (25.9 ± 12.7 reps) than the AER group (9.0 ± 8.3 reps). Sit-up performance in the MEN group (48.8 ± 14.3 reps) was significantly greater than all women's groups at T1 except the TP and UP groups. The TP, UP, TH, and UH groups, however, performed a significantly greater number of sit-ups than the MEN group

at T3. Sit-up performance in the MEN group remained greater than the AER group and was similar to the FLD group at T3.

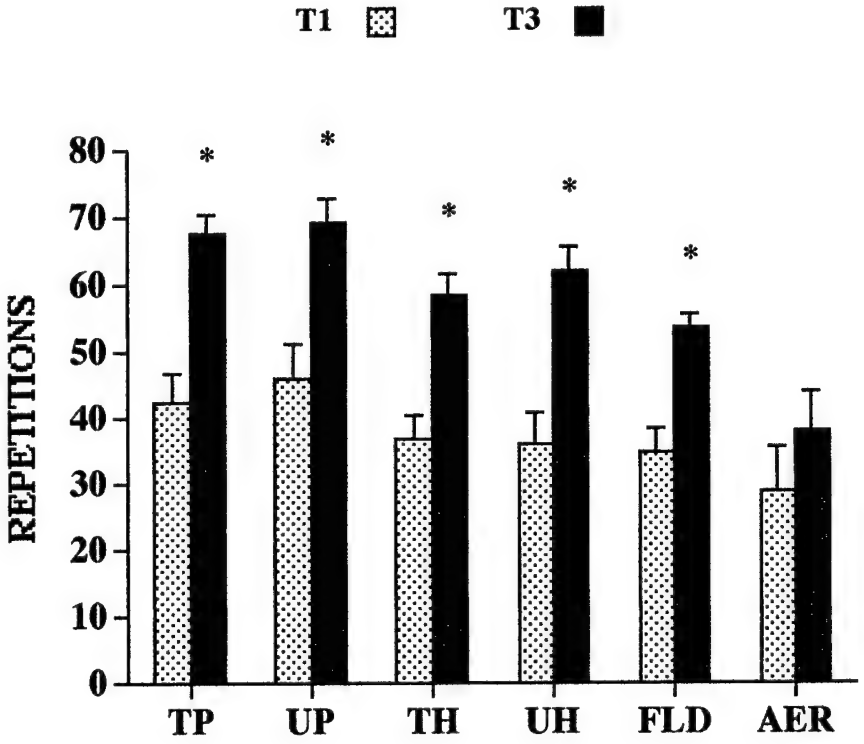


Figure 10. Comparison of sit-up performance (reps) at Baseline (T1) and following 6 months (T3) of total strength/power (TP), upper strength/power (UP), total hypertrophy (TH), upper hypertrophy (UH), field/ballistic plyometric (FLD), or aerobic/light resistance band training (AER). * $P < 0.05$ vs. corresponding T1 value. Values are means ± SE.

Interestingly all the training programs, except for the AER program helped the women surpass the men (sit ups 48.8) in the number of sit ups except the FLD group who were not significantly different from the norm for men. The AER group did not significantly change. It must be remembered that the resistance training groups were performing loaded sit ups in their training programs. All of the groups increased but again the use of loaded movements helped the resistance

training groups make better improvements over time. This has also been seen in men over three months of training (Kraemer et al., 1987).

2 mile Run. No differences were observed among the groups in 2m run time at T1 (Figure 10). Group x time interaction for 2m run was not significant. Two mile run time was significantly reduced (i.e, faster times) following training in all groups. Differences among groups in 2m run time at T3 included faster times in the TP, UP, TH, and UH groups as compared to the FLD group. Also at T3, the UP group ran the 2m run in less time than the AER group. Delta change in 2m run from T1 to T3 was greatest in the AER group (-128.44 ± 71.93 s), however, no differences were observed in the delta changes among any groups. Two mile run time in the MEN group (1012.6 ± 174.8 s) was significantly less than all women's groups at all experimental testing sessions except the UP group at T3 (1061.2 ± 112.5 s).

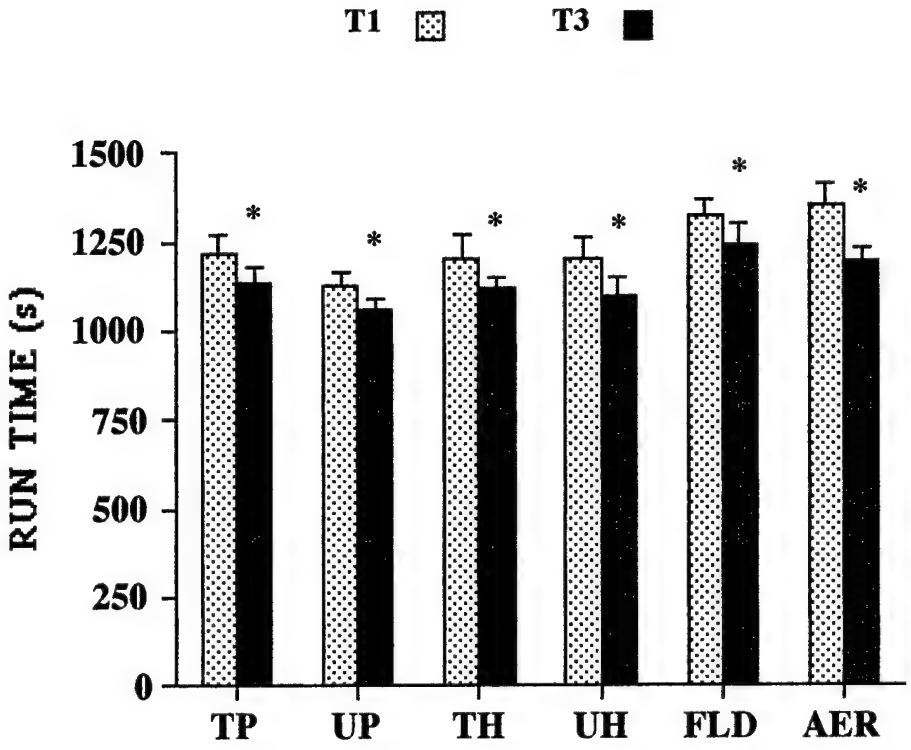


Figure 10. Comparison of 2 mile run time (s) at Baseline (T1) and following 6 months (T3) of total strength/power (TP), upper strength/power (UP), total hypertrophy (TH), upper hypertrophy (UH), field/ballistic plyometric (FLD), or aerobic/light resistance band training (AER). Values are means ± SE.

As expected all groups improved in the 2m run time. The endurance training component was part of a total conditioning program for all groups. It might be speculated that further improvements may have been achieved if longer amounts of time per session were dedicated to this conditioning component. However, this would place further time demands on the soldier to address all aspects of physical conditioning. However, even with 35 minutes of endurance in the training zone as periodized in the AER group, greater gains in the 2m run time were not observed lending less support to this general hypothesis as it relates to realistic addition of

time demands. It might take a much greater amount of time with different training methods to achieve high level aerobic fitness in a training program. The improvement of each groups run times approached the men and the UP group eventually were not significantly different from them. The cardiovascular differences between men and women may help to explain gender difference in performance (Fleck and Kraemer, 1997).

Military Relevant Work Tasks

1-RM Box Lift. No differences were observed among groups in 1-RM box lift at T1 (Figure 11). Significant interaction occurred between groups in 1-RM box lift during training. One-RM box lift increased significantly from T1 to T2 in the four resistance training groups. Only in the TP did significant increases continue to occur from T2 to T3. However, all resistance training groups T3 were significantly greater than T1. At T2, the 1-RM box lift was heavier in the resistance training groups than the AER group. Differences among groups in 1-RM box lift at T3 included greater performance in the all four resistance training groups as compared to the AER group. Delta changes (mean ± SD) in 1-RM box lift from T1 to T3 were significantly greater in the TP (8.1 ± 2.6 kg), UP (6.0 ± 3.2 kg), TH (7.8 ± 4.0 kg), and UH (7.2 ± 4.1 kg) groups than the AER group (9.3 ± 14.5 kg). The 1-RM box lift (mean ± SD) in the MEN group (57.4 ± 12.3 kg) was significantly heavier than all women's groups at all time points (heaviest women's value = 38.6 ± 6.7 kg in the TP group at T3).

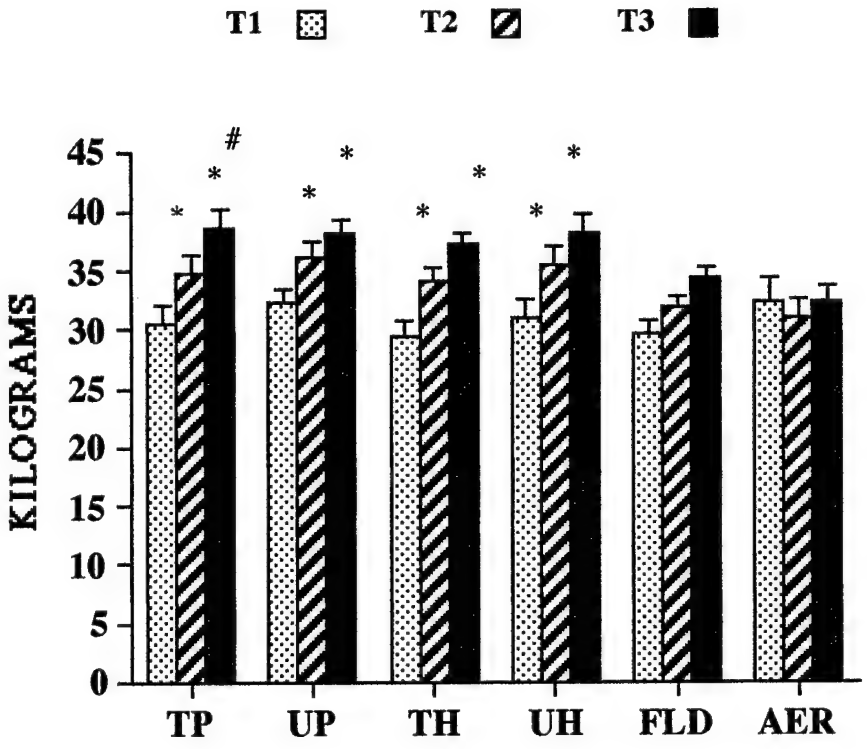


Figure 11. Comparison of 1-RM box lift performance (kg) at Baseline (T1) and following 3 (T2) and 6 months (T3) of total strength/power (TP), upper strength/power (UP), total hypertrophy (TH), upper hypertrophy (UH), field/ballistic plyometric (FLD), or aerobic/light resistance band training (AER). * $P < 0.05$ vs. corresponding, # $P < 0.05$ vs. corresponding T2 value. Values are means ± SE.

Again, the improvement in 1 RM box lift was seen for all groups with the exception of the FLD group. These data demonstrate that the upper body plays a crucial role in this military task. This is most likely due to the last part of the movement where the box is thrust out onto the landing. The lack of enhancement from the lower body training for changes is unclear unless the biomechanics of the test are limited by this final phase of the test movement. The continued consecutive gains made by the TP group in this 1 RM box lift may again be due to more resistive exercise with explosive multi-joint exercises. The lack of change in the FLD group may be due to limited impact of the upper body exercises on the test movement and no way for the explosive plyometric exercises of the lower body to be transferred to this test skill. This predominance of upper body strength/power component was again supported by the significantly greater performance in the men.

Repetitive Box Lift. Differences among groups in repetitive box lift at T1 included greater performance in the TP, UP, and TH groups as compared to the FLD and AER groups (Figure 12). Significant interaction occurred between groups in repetitive box lift during training. Repetitive box lift performance increased significantly from T1 to T2 in the TP, UP, TH, and UH groups. At T2, the repetitive box lift performance was greater in the TP, UP, TH, and UH groups than the FLD and AER groups. Repetitive box lift performance increased significantly from T1 to T3 in all groups except the AER group. Repetitive box lift performance also was greater in the TP, UP, TH, and UH groups than the FLD and AER groups at T3. Delta change in repetitive box lift from T1 to T3 was greatest in the UH group

(33.5 ± 14.1 boxes), however, no differences were observed in the delta changes among any groups. Repetitive box lift performance in the MEN group (131.0 ± 22.0 boxes) was significantly greater than all women's groups at all experimental testing sessions except the UP group at T3 (122.1 ± 17.5 boxes).

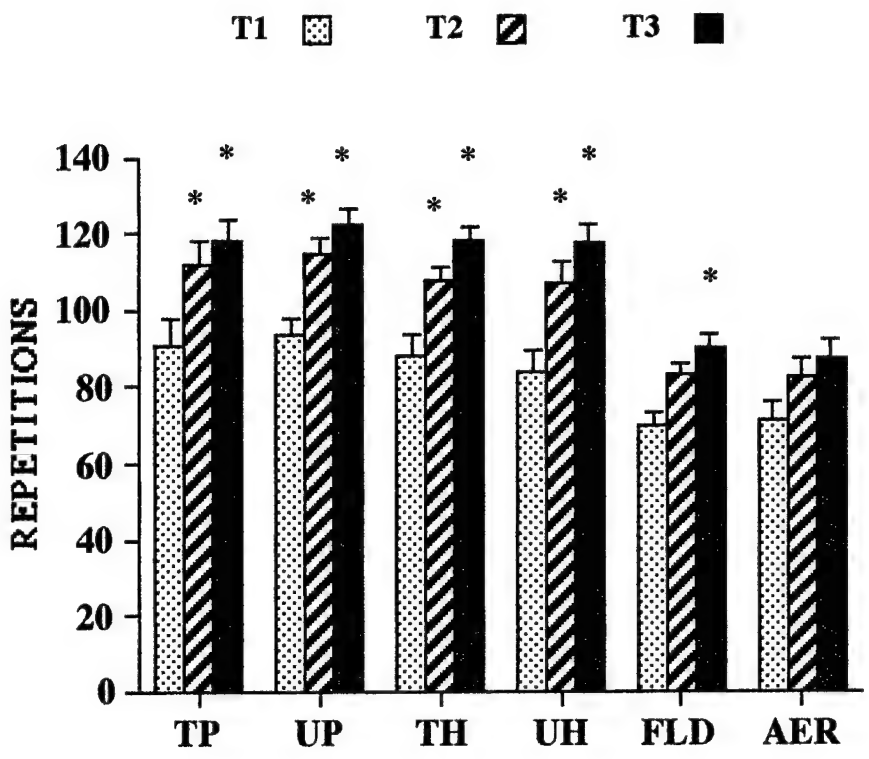


Figure 12. Comparison of Repetitive Box Lift performance (kg) at Baseline (T1) and following 3 (T2) and 6 months (T3) of total strength/power (TP), upper strength/power (UP), total hypertrophy (TH), upper hypertrophy (UH), field/ballistic plyometric (FLD), or aerobic/light resistance band training (AER). * $P < 0.05$ vs. corresponding T1 value. Values are means ± SE.

This test demanded a combination of physiological components including both endurance and strength/power capabilities. The greatest magnitude of gains with this test were observed over the first three months. As with all of the tests, high realiability was associated with them thus limiting the argument for any "learning effects". The larger magnitude of change over the first three months of training could be speculated to be due to a "work hardening" effect as this test was the

most demanding work task both psychologically and physiologically. The average score for the men (131) was still higher than the women in all groups and again maybe due to the greater upper body strength and power which was shown to be important in this work task. Nevertheless, this work task was capable of being significantly trained in a short period of time (3 months).

2 Mile (2m) Load Run. No differences were observed among groups in 2m load run at T1 (Figure 13). Group x time interaction for 2m load run was not significant. Further analysis of the T3 values revealed that the 4 resistance training groups ran the 2m load run in significantly less time than the AER group at T3. Also, the UP group ran the 2m load run in significantly less time than the FLD group at T3. Delta change in 2m load run from T1 to T3 was greatest in the UP group (-209.2 ± 220.8 s), however, no differences were observed in the delta changes among any groups. The FLD group showed a trend (P = 0.08) for a significant reduction. The MEN group (1702.5 ± 331.1 s) ran the 2m load run in significantly less time than all of the women's groups at T1. **Following TP, UP, TH, and UH training, however, women were able to run with a 34.1 kg rucksack at a similar pace as the MEN group**. The MEN group ran the 2m load run in less time as compared to the FLD and AER groups at T3.

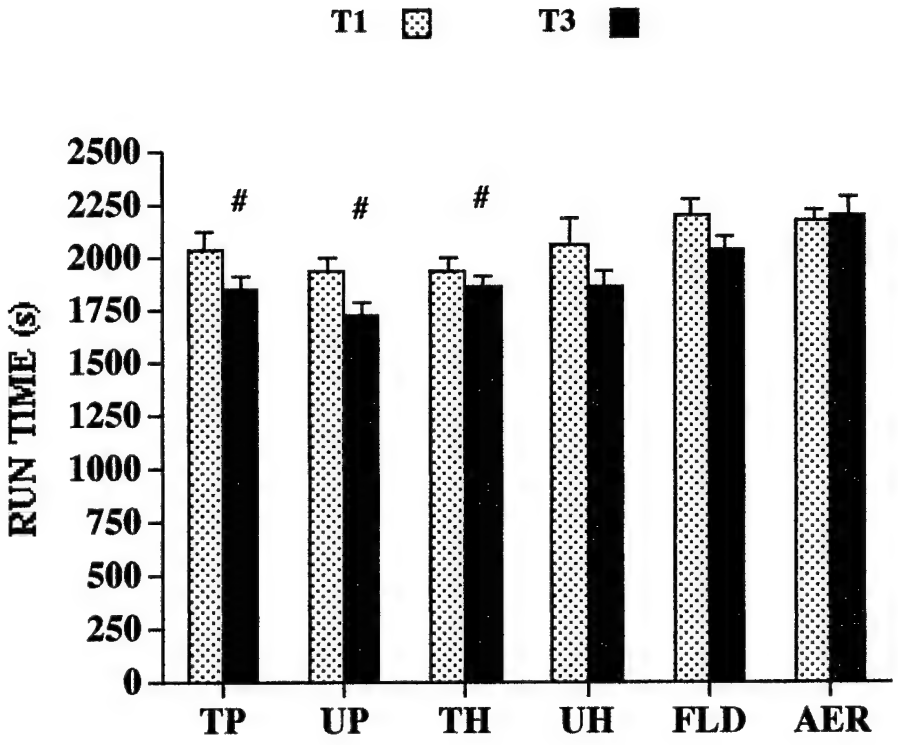


Figure 13. Comparison of 2m load run time (s) at Baseline (T1) and following 6 months (T3) of total strength/power (TP), upper strength/power (UP), total hypertrophy (TH), upper hypertrophy (UH), field/ballistic plyometric (FLD), or aerobic/light resistance band training (AER). # $P < 0.05$ vs. corresponding T1 value. Values are means ± SE.

As was shown by Kraemer et al (1987), upper body training and strength/power training in general enhances load carriage even when the load carriage is not practiced. While load carriage and training can enhance performance in women (Harman et al., 1998), our data show that this transfer can take place without load

carriage practice thus reducing the soldier to overuse injury stress. Furthermore, aerobic endurance training alone will not enhance load carriage as shown in this study as well as in the previous study of men (Kraemer et al., 1987). The carriage of load is significantly affected by the ability of the upper body for structural support in posture which also affects the mechanics of locomotion.

Summary Physical Perfomance. Many of the physical performance adaptations demonstrate that initial short-term training maybe adequate. This would make logistical preparations for fitness in women somewhat easier but it must be noted that in more recent unpublished studies in my (PI: WJK) laboratory over longer training periods of time (9 months) a flattening of training effects do occur somewhere between 4 and 6 months and then start to increase again. We really have little understanding of the "building progression" in men or women and it is assumed to have an upper limit based on genetics.

BODY COMPOSITION

Body composition using the skin folds and the U.S. Army circumfernece measure were compared in this study. In addition, body mass was evaluated as one of the fears of many women is that they may gain weight with a resistance training program and fear "big muscles".

Body Mass. No differences were observed among groups in body mass at T1 (Figure 14). Significant interaction occurred between groups in body mass during training. No significant training effects for body mass were observed. Body mass was greater in the FLD and AER groups than the TH group at T2. At T3, body

mass was greater in the FLD group than the TH group. Delta change in body mass from T1 to T3 was greatest in the TP group (2.99 ± 3.6 kg), however, no differences were observed in the delta changes among any groups. Body mass in the MEN group (78.7 ± 9.4 kg) was significantly greater than all women's groups at all experimental testing sessions (highest women's value = 68.9 ± 10.6 kg in the AER group at T1).

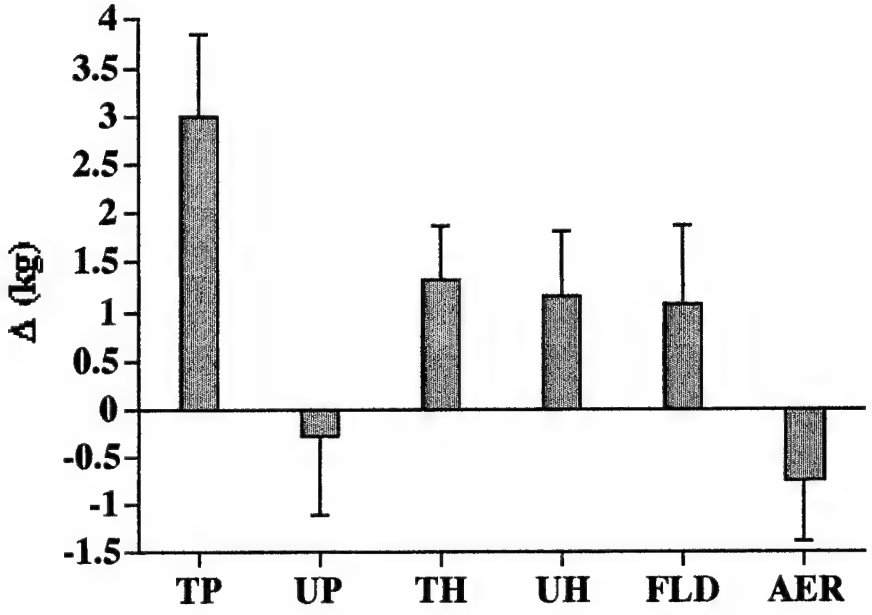


Figure 14. Comparison of change in body mass (kg) following total strength/power (TP), upper strength/power (UP), total hypertrophy (TH), upper hypertrophy (UH), field/ballistic plyometric (FLD), or aerobic/light resistance band training (AER). Values are means ± SE.

Fat Mass. No differences were observed among groups in fat mass at T1, T2, or T3 (Figure 15). Group x time interaction for fat mass was not significant. No significant training effects for fat mass were observed. Delta change in fat mass from T1 to T3 was greatest in the AER group (-1.74 ± 2.1 kg), however, no differences were observed in the delta changes among any groups. Fat mass in the MEN group (13.4 ± 6.6 kg) was less at all time points than all of the women's groups except the TH group at T1, T2, and T3 (about 15 kg).

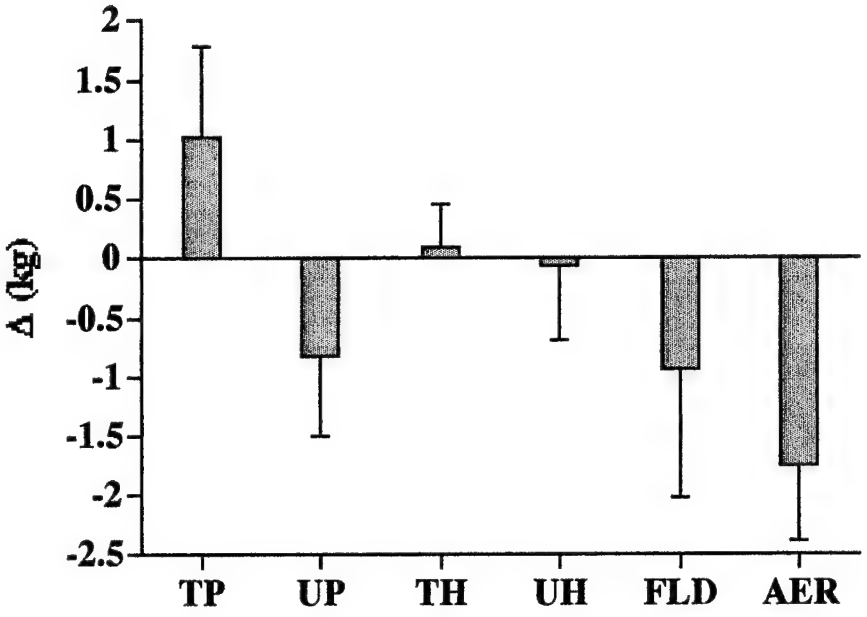


Figure 15. Comparison of change in fat mass (kg) following total strength/power (TP), upper strength/power (UP), total hypertrophy (TH), upper hypertrophy (UH), field/ballistic plyometric (FLD), or aerobic/light resistance band training (AER). Values are means ± SE.

Fat-Free Mass. No differences were observed among groups in fat-free mass at T1, T2, or T3 (Figure 16). Group x time interaction for fat-free mass was not significant. No significant training effects for fat-free mass were observed. Delta changes in fat-free mass from T1 to T3 were greatest in the FLD (1.99 ± 3.2 kg) and TP groups (1.98 ± 1.8 kg), however, no differences were observed in the delta changes among any groups. Fat-free mass in the MEN group (65.3 ± 5.7 kg) was greater than all of the women's groups at all experimental testing sessions (highest women's value = 49.7 ± 5.4 kg in the UP group at T3).

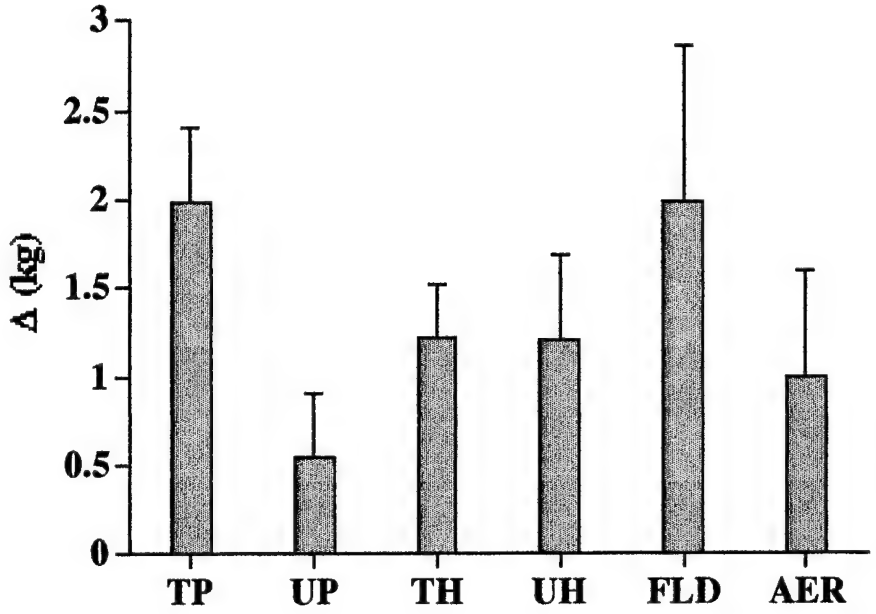


Figure 16. Comparison of change in fat-free mass (kg) following total strength/power (TP), upper strength/power (UP), total hypertrophy (TH), upper hypertrophy (UH), field/ballistic plyometric (FLD), or aerobic/light resistance band training (AER). Values are means ± SE.

Skinfolds % Body Fat. Skinfolds percent body fat (SF % BF) was significantly less in the TH group than the FLD and AER groups at T1 (Figure 17). Other differences among groups in SF % BF at T1 included lower % fat in the UP group than the AER group. Group x time interaction for SF % BF was not significant. No significant training effects for SF % BF were observed. No differences were observed among groups in SF % body fat at T2, or T3. Delta change in SF % body fat from T1 to T3 was greatest in the AER group (-2.23 ± 2.6 %), however, no differences were observed in the delta changes among any groups. Skinfolds % BF in the MEN group (16.5 ± 6.4 %) was lower than all of the women's groups at all

experimental testing sessions (lowest women's value = 23.0 ± 4.7 % in the TH group at T2).

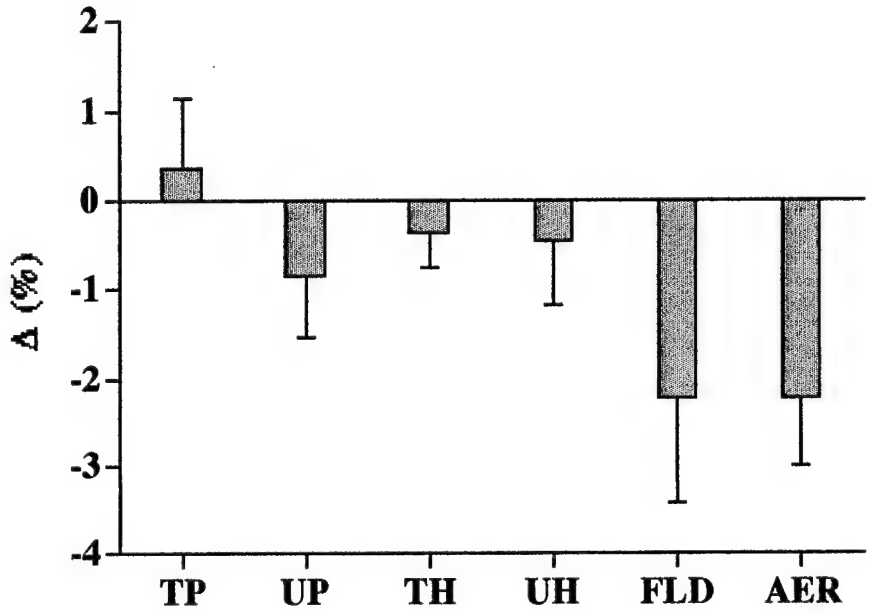


Figure 17. Comparison of change in skinfolds % body fat following total strength/power (TP), upper strength/power (UP), total hypertrophy (TH), upper hypertrophy (UH), field/ballistic plyometric (FLD), or aerobic/light resistance band training (AER). Values are means ± SE.

Army % Body Fat. No differences were observed among groups in ARMY % BF at T1 (Figure 18). Significant interaction occurred between groups in ARMY % BF during training. No significant training effects for ARMY % BF were observed. No differences were observed among groups in ARMY % body fat at T2. ARMY % BF was less in the UP, TH, and UH groups than the FLD and AER groups at T3. Other differences among groups in ARMY % BF at T3 included less % fat in the TP group than the AER group. Delta change in ARMY % body fat from T1 to T3 was greatest in the UP group (-1.48 ± 1.6 %), however, no differences were observed in the delta changes among any groups. ARMY % BF in the MEN group (16.7 ± 4.7 %) was lower

than all of the women's groups at all experimental testing sessions (lowest women's value = 26.9 ± 3.9 % in the TH group at T1).

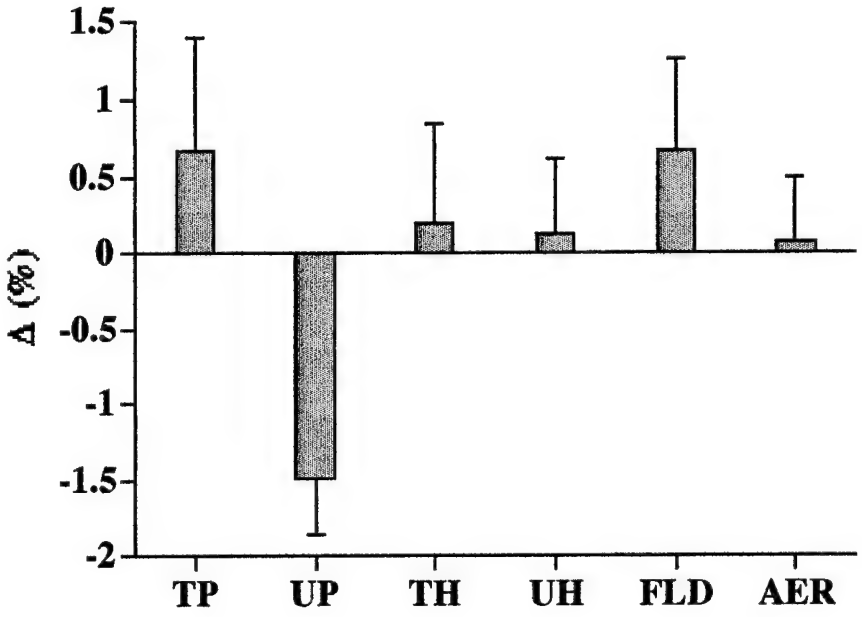


Figure 18. Comparison of change in ARMY % body fat following total strength/power (TP), upper strength/power (UP), total hypertrophy (TH), upper hypertrophy (UH), field/ballistic plyometric (FLD), or aerobic/light resistance band training (AER). Values are means ± SE.

One of the biggest fears of women is that they will get big and gain weight with a resistance training program. In this study we showed that while local muscle hypertrophy occurs the training related changes do not really translate to heavier body mass in the women over the six month training period. Most likely this was due to an interaction of fat and muscle compartments. While hypertrophy of muscle occurred in both the arms and thighs of the resistance training groups no significant body mass increases were observed. However a trend (P=0.08) did exist for the TP group. The aerobic group as expected also had a trend (P =0.10)

for a significant loss in weight. In this study no attempt was made to control for the increases in caloric intake, only the inadequacy of the caloric intake to support training related adaptations. The localized muscular hypertrophy coupled with minimal losses in body fat mass may help explain the changes observed although the use of indirect techniques to analyze body composition in this study make direct statements about this aspect of the composition change difficult at best.

Body composition in this study showed that localized hypertrophy occurred in the resistance training group yet changes in the body composition were minimal. The use of indirect techniques may have contributed variance to these measures. However the test retest reliability of the procedures were high (Intra-class correlation of Rs > 0.98 for the techniques show in may be inherent validity that may be questionable. The correlation between skin folds and the U.S. Army circumference technique in this study were $r = 0.72$ or $r^2 = 0.53$ for all the women's testing (n=279) and $r = 0.79$ or $r^2 = 0.62$ for the whole group (n=100) of men. The amount of shared variance between the two testing procedures may account for some of the differences in the results observed.

Endocrine Responses

A number of endocrine factors were examined to determine if there were underlying changes going on in the physiological milieu to help explain the anabolic and catabolic changes observed in muscle and ultimately performance.

Total and Free Testosterone

Total Testosterone. Total testosterone concentrations increased significantly from resting values immediately following an acute heavy-resistance exercise bout (post-exercise) in the UP and TH groups at T1, T2, and T3 (Figure 19). Significant increases in post-exercise total testosterone concentrations were also observed in the TP group at T1 and T2, and in the UH group at T1. No differences were observed among groups in resting total testosterone concentrations at T1 (Figure 20). Significant interaction occurred between groups in resting total testosterone concentrations during training. At T2, resting total testosterone concentration was greater in the UP group than the TH group. Resting total testosterone concentrations increased significantly from T1 to T3 in the TP and UP groups, and from T2 to T3 in the UP group. Differences among groups in resting total testosterone at T3 included greater concentrations in the TP group than the UP, TH, and UH groups. Delta change in resting total testosterone concentration from T1 to T3 was significantly greater in the TP group (0.39 ± 0.77 nmol/l) than the UP group (-0.31 ± 0.44 nmol/l).

No differences were observed among groups in post-exercise total testosterone concentrations at T1 (Figure 21). Significant interaction occurred between groups in post-exercise total testosterone concentrations during training. Differences among groups in post-exercise total testosterone at T2 included greater concentrations in the UP group than the TH and UH groups. Post-exercise total testosterone concentrations increased significantly from T1 to T3 in the TP and UP groups, and from T2 to T3 in the UP group. Also, post-exercise total testosterone concentration decreased significantly from T1 to T3 in the UH group.

Differences among groups in post-exercise total testosterone at T3 included greater concentrations in the TP group than the UP and UH groups. Also at T3, post-exercise total testosterone concentrations were greater in the TH group than the UH group. Delta changes in post-exercise total testosterone concentrations from T1 to T3 were significantly greater in the TP (0.32 ± 0.66 nmol/l) and TH groups (0.19 ± 0.47 nmol/l) than the UP (-0.27 ± 0.40 nmol/l) and UH groups (-0.28 ± 0.53 nmol/l).

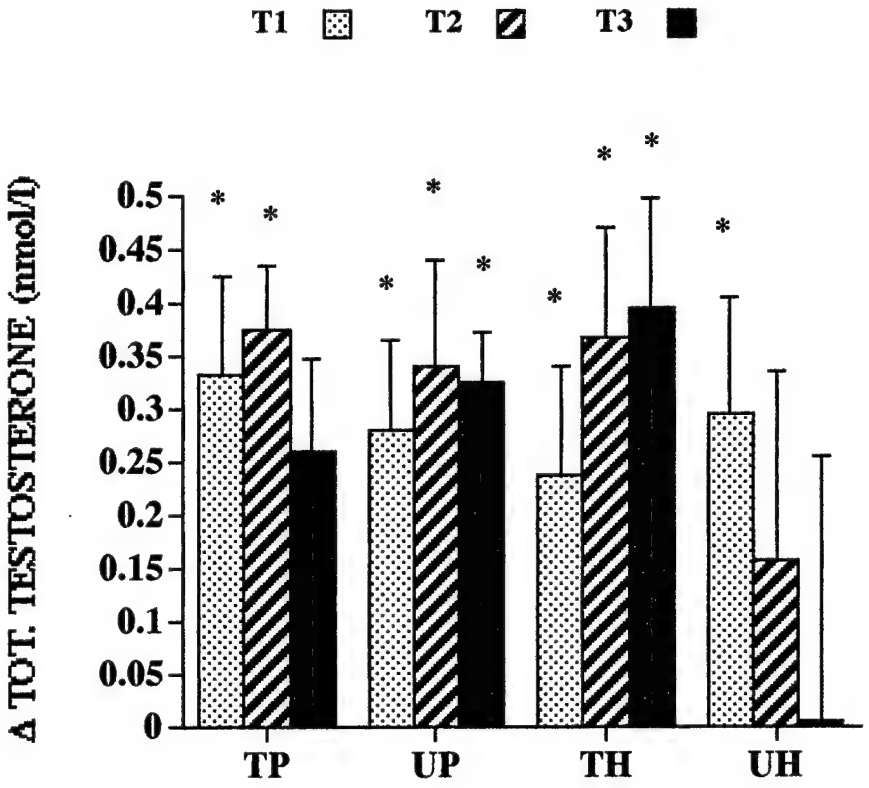


Figure 19. Changes in total (TOT.) testosterone concentrations (nmol/l) following an acute heavy-resistance exercise bout for Total Strength/Power (TP), Upper Strength/Power (UP), Total Hypertrophy (TH), and Upper Hypertrophy (UH) groups before (T1), and after 3 (T2) and 6 months of training (T3). * = $P < 0.05$ for the Δ from pre- to post-heavy-resistance exercise bout

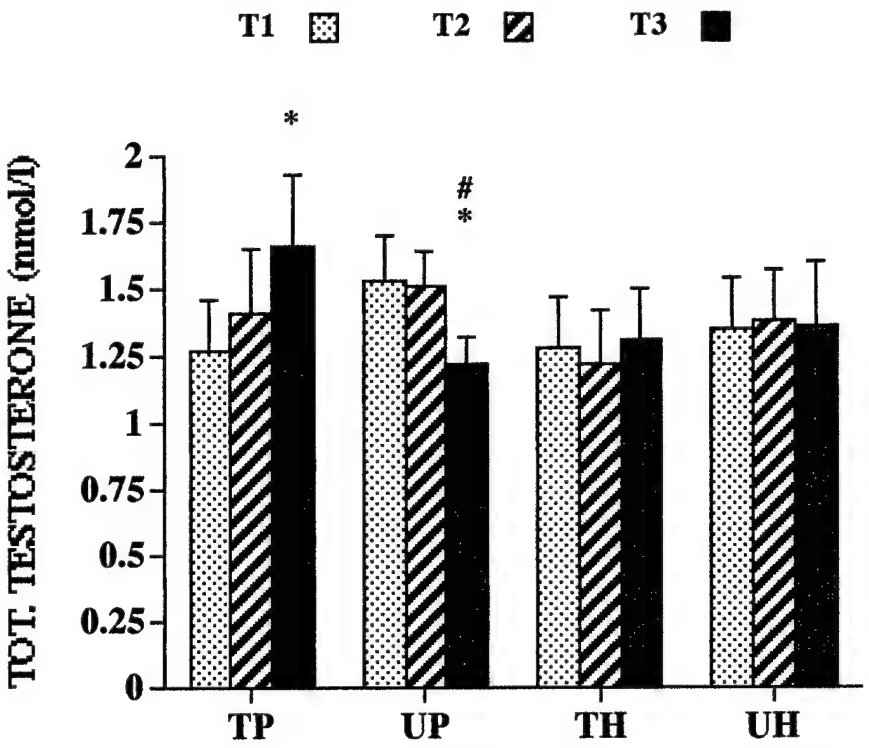


Figure 20. Resting total (TOT.) testosterone concentrations (nmol/l) among Total Strength/Power (TP), Upper Strength/Power (UP), Total Hypertrophy (TH), and Upper Hypertrophy (UH) groups before (T1), and after 3 (T2) and 6 months of training (T3).
* = $P < 0.05$ vs corresponding T1 value, # = $P < 0.05$ vs corresponding T2 value

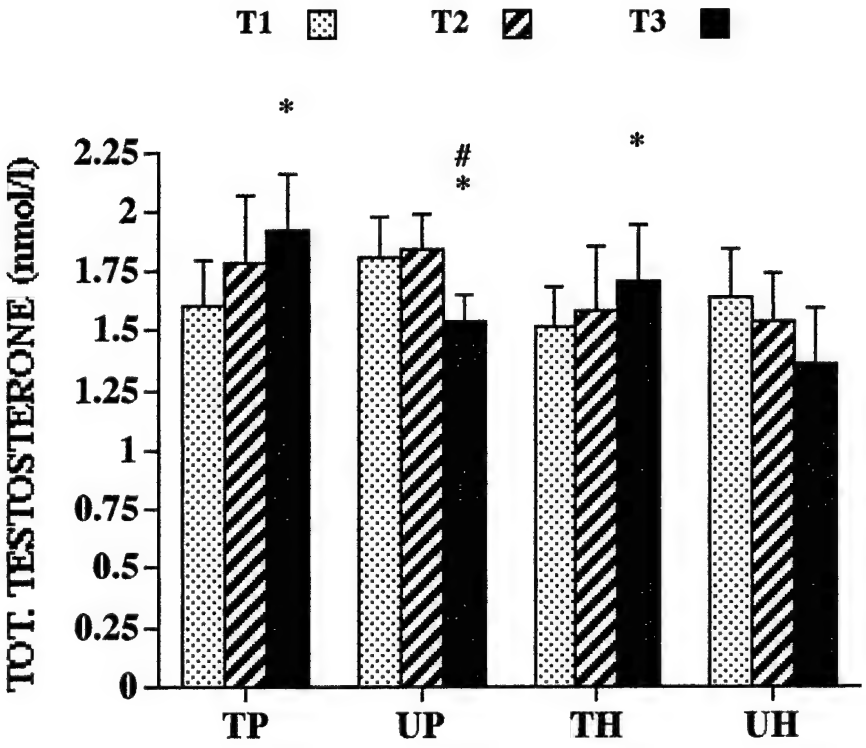


Figure 21. Total testosterone (TEST.) concentrations (nmol/l) immediately following an acute heavy-resistance exercise bout among Total Strength/Power (TP), Upper Strength/Power (UP), Total Hypertrophy (TH), and Upper Hypertrophy (UH) groups before (T1), and after 3 (T2) and 6 months of training (T3). * = $P < 0.05$ vs corresponding T1 value, # = $P < 0.05$ vs corresponding T2 value

Free Testosterone. Free testosterone concentrations increased significantly from resting values immediately following an acute heavy-resistance exercise bout (post-exercise) in the TP, UP, and TH groups at T1, T2, and T3 (Figure 22). Significant increases in post-exercise free testosterone concentrations were also observed in the UH group at T2 and T3. No differences were observed among groups in resting free testosterone concentrations at T1 (Figure 23). Significant interaction occurred between groups in resting free testosterone concentrations

during training. No differences were observed among groups in resting free testosterone concentrations at T2. Resting free testosterone concentrations increased significantly from T1 to T3 in the TP and UP groups. Differences among groups in resting free testosterone at T3 included greater concentrations in the TP group than the UP, TH, and UH groups. Delta change in resting free testosterone concentration from T1 to T3 was significantly greater in the TP group (2.96 ± 5.07 nmol/l) than the UP (-2.28 ± 2.82 nmol/l) and UH groups (-1.09 ± 2.45 nmol/l). Also, delta change in resting free testosterone concentration from T1 to T3 was greater in the TH group (0.64 ± 2.48 nmol/l) than the UP group.

No differences were observed among groups in post-exercise free testosterone concentrations at T1 (Figure 24). Significant interaction occurred between groups in post-exercise free testosterone concentrations during training. No differences were observed among groups in post-exercise free testosterone concentrations at T2. Post-exercise free testosterone concentrations increased significantly from T1 to T3 and T2 to T3 in the TP and UP groups. Differences among groups in post-exercise free testosterone at T3 included greater concentrations in the TP group than the UP, TH, and UH groups. Delta change in post-exercise free testosterone concentration from T1 to T3 was significantly greater in the TP group (1.97 ± 4.39 nmol/l) than the UP (-3.14 ± 2.59 nmol/l) and UH groups (-1.08 ± 2.43 nmol/l). Also, delta change in post-exercise free testosterone concentration from T1 to T3 was greater in the TH group (0.88 ± 3.2 nmol/l) than the UP group.

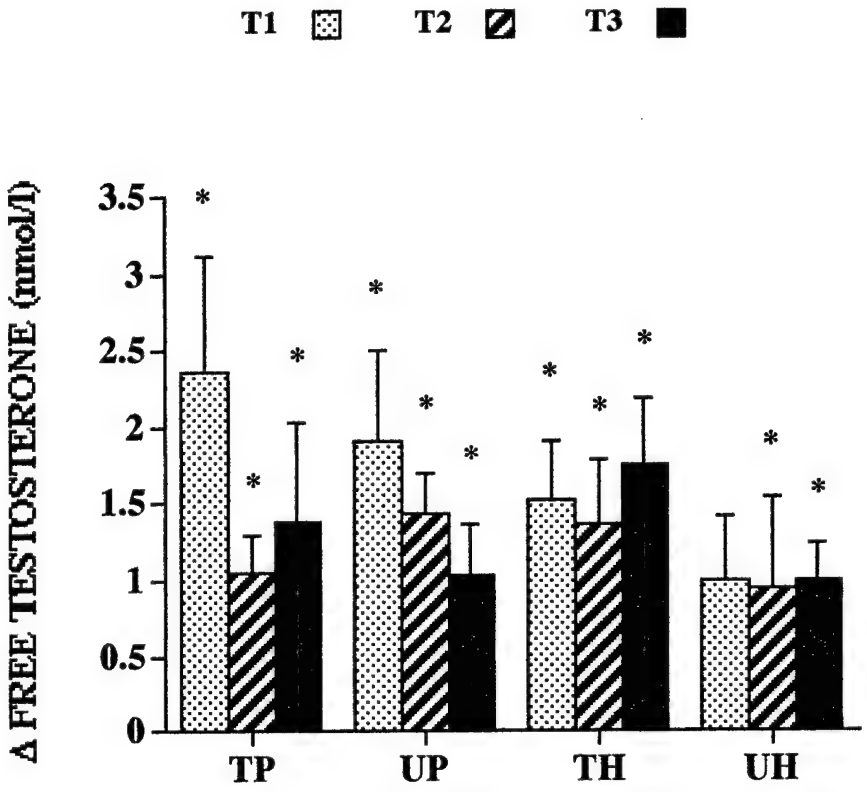


Figure 22. Changes in free testosterone concentrations (nmol/l) following an acute heavy-resistance exercise bout for Total Strength/Power (TP), Upper Strength/Power (UP), Total Hypertrophy (TH), and Upper Hypertrophy (UH) groups before (T1), and after 3 (T2) and 6 months of training (T3). * = $P < 0.05$ for the Δ from pre- to post-heavy-resistance exercise bout

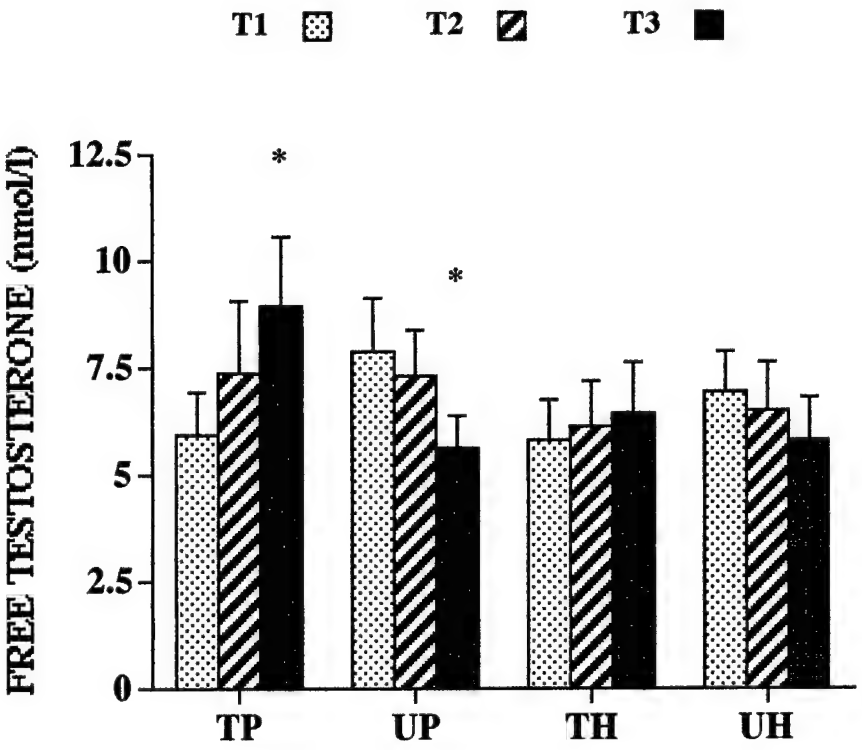


Figure 23. Resting free testosterone concentrations (nmol/l) among Total Strength/Power (TP), Upper Strength/Power (UP), Total Hypertrophy (TH), and Upper Hypertrophy (UH) groups before (T1), and after 3 (T2) and 6 months of training (T3). * = $P < 0.05$ vs corresponding T1 value

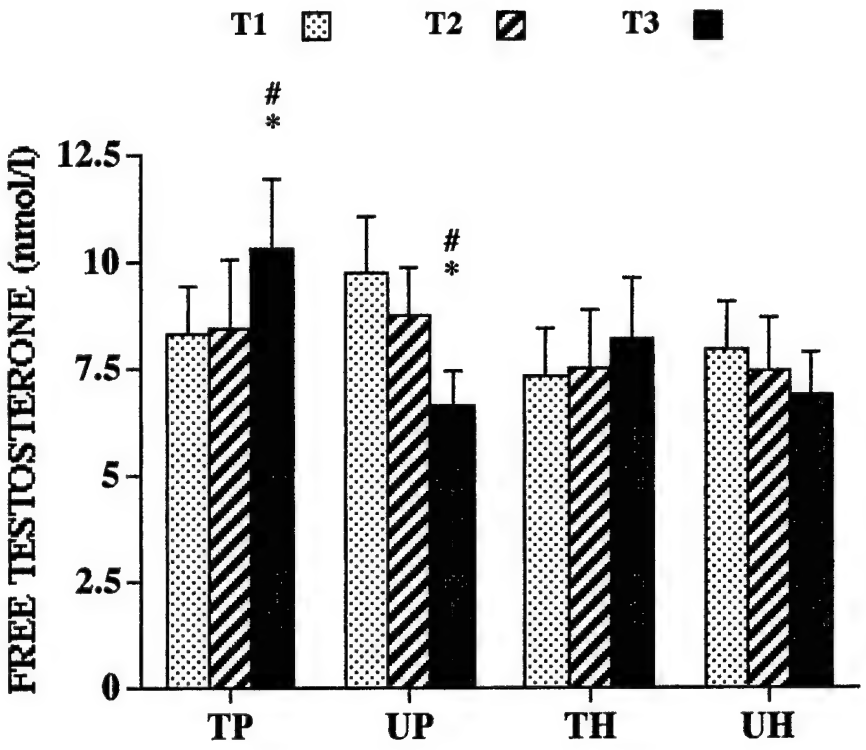


Figure 24. Free testosterone concentrations (nmol/l) immediately following an acute heavy-resistance exercise bout among Total Strength/Power (TP), Upper Strength/Power (UP), Total Hypertrophy (TH), and Upper Hypertrophy (UH) groups before (T1), and after 3 (T2) and 6 months of training (T3). * = $P < 0.05$ vs corresponding T1 value, # = $P < 0.05$ vs corresponding T2 value

Prior studies have not been able to demonstrate acute or chronic changes in testosterone responses in women (Kraemer et al., 1991; 1993; Häkkinen et al. 1990; Westerlind et al., 1987). This study had the statistical power to demonstrate small but significant changes in the adrenal responses of the women. It might be postulated that the impact to both nerve and muscle were significant. It has been shown that small increases in testosterone in women is reflected by the increases in binding proteins to protect this fraction.

Serum Cortisol

Cortisol concentrations increased significantly from resting values immediately following an acute heavy-resistance exercise bout (post-exercise) in the TP group at T1, T2, and T3 (Figure 24). Significant increases in post-exercise cortisol concentrations were also observed in the TH group at T1 and T2. No differences were observed among groups in resting cortisol concentrations at T1. Group x time interaction for resting cortisol concentrations was not significant. Differences among groups in resting cortisol at T2 included greater concentrations in the TP group than the TH group. Also at T2, resting cortisol concentrations were greater in the UH group than the UP and TH groups. No significant time (i.e., training) effects were observed in resting cortisol concentrations. Differences among groups in resting cortisol at T3 included greater concentrations in the TP group than the UP group. Also at T3, resting cortisol concentrations were greater in the UH group than the UP and TH groups. Delta changes (Figure 25) in resting cortisol concentration from T1 to T3 was significantly greater in the TP group (308.14 ± 503.35 nmol/l) than the UP group (-100.63 ± 279.53 nmol/l).

No differences were observed among groups in post-exercise cortisol concentrations at T1 (Figure 26). Group x time interaction for post-exercise cortisol concentrations was not significant. No differences were observed among groups in post-exercise cortisol concentrations at T2. No significant time (i.e., training) effects were observed in post-exercise cortisol concentrations. Differences among groups in post-exercise cortisol at T3 included greater concentrations in the TP and UH groups than the UP group. Delta change in post-exercise cortisol concentration from T1 to T3 was greatest in the TP group

(239.99 ± 534.16 nmol/l), however, no differences were observed in the delta changes among any groups.

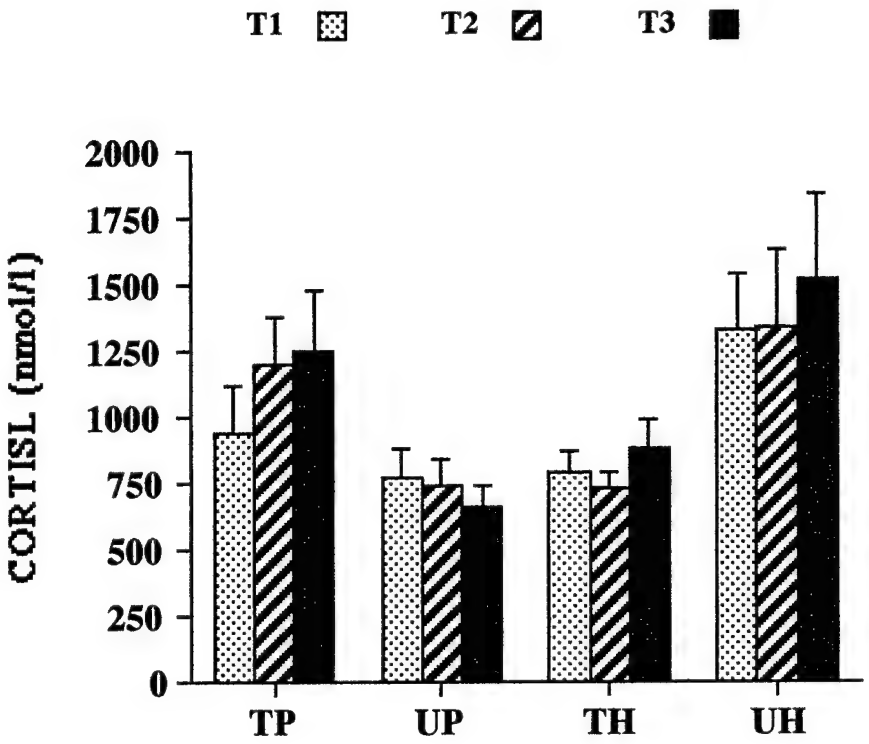


Figure 24. Resting cortisol concentrations (nmol/l) among Total Strength/Power (TP), Upper Strength/Power (UP), Total Hypertrophy (TH), and Upper Hypertrophy (UH) groups before (T1), and after 3 (T2) and 6 months of training (T3).

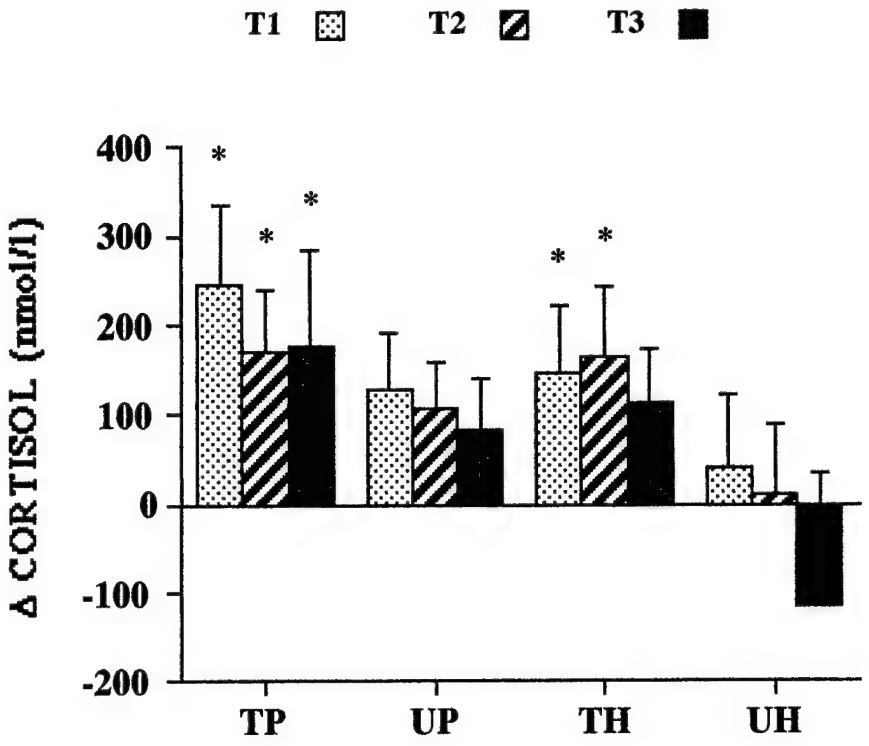


Figure 25. Changes (Δ) in cortisol concentrations (nmol/l) following an acute heavy-resistance exercise bout for Total Strength/Power (TP), Upper Strength/Power (UP), Total Hypertrophy (TH), and Upper Hypertrophy (UH) groups before (T1), and after 3 (T2) and 6 months of training (T3). * = $P < 0.05$ for the Δ from pre- to post-heavy-resistance exercise bout

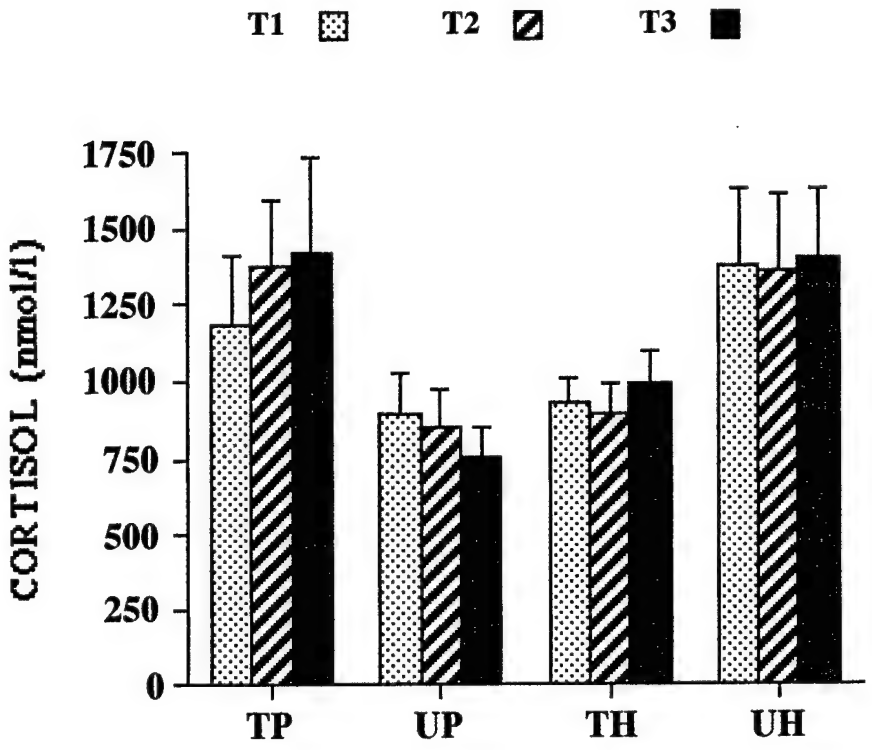


Figure 26. Cortisol concentrations (nmol/l) immediately following (post-exercise) an acute heavy-resistance exercise bout among Total Strength/Power (TP), Upper Strength/Power (UP), Total Hypertrophy (TH), and Upper Hypertrophy (UH) groups before (T1), and after 3 (T2) and 6 months of training (T3).

Testosterone and Cortisol Responses

The results of this study show that women do have a dynamic system of adaptation as it relates to the production of testosterone, most likely from the adrenal cortex. Different from prior studies which have not been able to show such small but significant changes with resistance exercise or training, this study had the statistical power to partial out such effects. In a regression analysis, it was demonstrated that testosterone accounts for about 10 percent of the development of muscle size in women. In general , the changes appear to be similar

for both upper and total body resistance training programs indicating that the stimulation of the upper body musculature is also enough muscle tissue to bring about alterations in the body. The lack of changes in cortisol, in general, may be offset by the changes in the androgens at the level of the receptor as it has been found that cortisol's negative effects can be inhibited with training by testosterone. As one of the biological mechanisms of adaptation the anabolic actions of testosterone and changes in cortisol may help to optimize the anabolic environment (Kraemer, 1992). Interestingly, the lack of changes in cortisol may be due to a proper nutrition program allowing adequate glycogen retention in the muscle limiting the signaling from cortisol to preserve glycogen beyond the acute training sessions where cortisol was found to increase, as expected in response to a resistance exercise protocol (Kraemer et al., 1993).

Insulin-Like Growth Factor-I

Insulin Like Growth Factor-1. IGF-1 concentrations increased significantly from resting values immediately following an acute heavy-resistance exercise bout (post-exercise) in the TP and TH groups at T1 and T3 (Figure 28). No differences were observed among groups in resting IGF-1 concentrations at T1. Group x time interaction for resting IGF-1 concentrations was not significant ($p = 0.069$). No significant time (i.e., training) effects were observed in resting IGF-1 concentrations. No differences were observed among groups in resting IGF-1 concentrations at T3. Delta change in resting IGF-1 concentration from T1 to T3 was greatest in the TP group (23.14 ± 47.58 ng/ml), however, no differences were observed in the delta changes among any groups.

No differences were observed among groups in post-exercise IGF-1 concentrations at T1. Group x time interaction for post-exercise IGF-1 concentrations was not significant. No significant time (i.e., training) effects were observed in post-exercise IGF-1 concentrations. No differences were observed among groups in post-exercise IGF-1 concentrations at T3. Delta change in post-exercise IGF-1 concentration from T1 to T3 was greatest in the TP group (11.14 ± 42.73 ng/ml), however, no differences were observed in the delta changes among any groups.

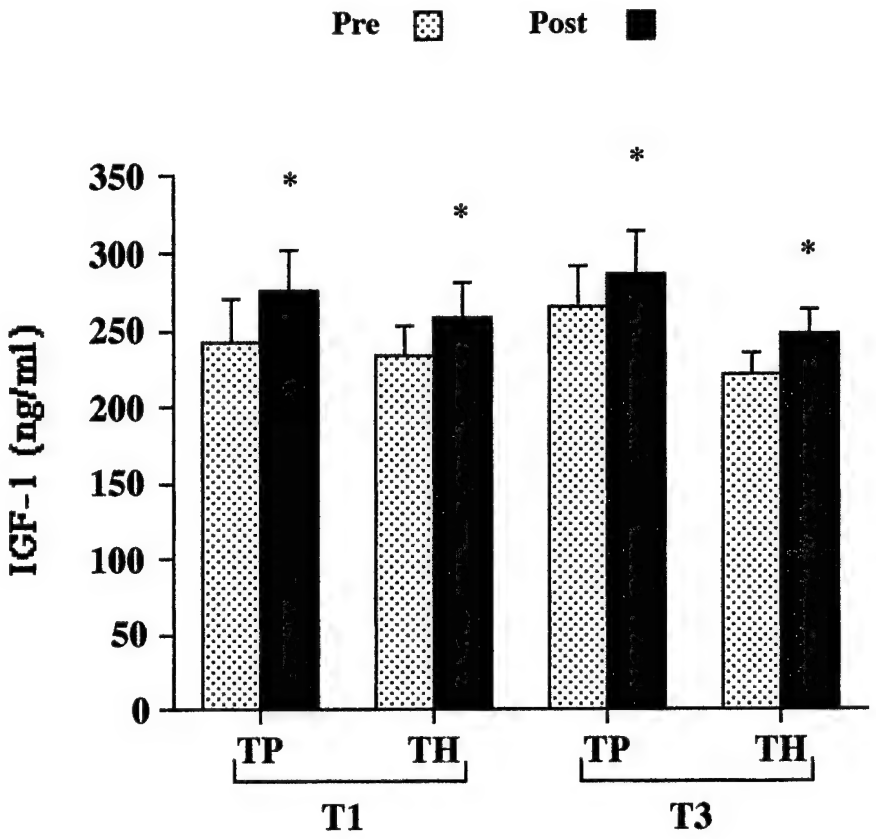


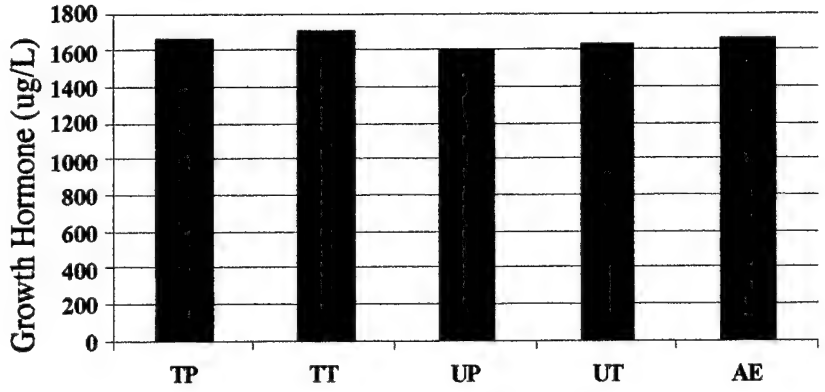
Figure 28. Insulin-Like Growth Factor-1 (IGF-1) concentrations (ng/ml) before (pre) and after (post) an acute heavy-resistance exercise bout among Total Strength/Power (TP) and Total Hypertrophy (TH) groups before (T1) and after 6 months of training (T3).
* = $P < 0.05$ vs corresponding Pre value

The lack of response of IGF-1 with chronic training were expected as prior work has indicated that unless a dramatic change in protien intake or shift in nitrogen balance occurs limited changes may be seen in the alteration of IGF-1 concentrations (Kraemer et al.1999). This hormone does not act as a typical endocrine entity and is more responsive to the over all 24 hour changes in GH. With a lack of changes in GH over time, except for the BGH post-exercise after 6 months of training it appears that it may be 22 kD GH molecule which is signaling the change.

Growth Hormone(s)

In this study, we examined bioassay (BGH) and immunoassay (IGH) responses of growth hormone to acute exercise (6 x 10 RM squat) and to physical conditioning. The main effects observed in the BGH were significant main effects for training and fraction, but not training groups or exercise. Figures 29 and 30 show the marginal means for training group and exercise, respectively. Figure 31 shows the marginal means for training illustrating increases in BGH after 6 months of physical training. Figure 32 shows the BGH in each of the fractions. The unfractionated samples had higher concentrations than all 3 fractionated samples; all three fractionated samples exhibited similar bioactivity. Figure 33 shows significant interaction effects were noted for "training X exercise". After six months of training, post-exercise BGH was greater than the corresponding pre-training value. Figures 34 and 35 illustrate the "fraction X exercise" and "fraction X training" interactions respectively.

With IGH the significant main effects were observed for fraction and exercise, but not for training group or training. Figure 36 shows that the unfractionated sample had the highest immunoreactivity and that fraction A had lower immunoreactivity than fractions B and C. Figure 37 shows the immunoreactivity among the training groups. Figures 38 and 39 show the marginal means due to exercise and training, respectively.



1

Figure 29. Bioassay GH for training group.

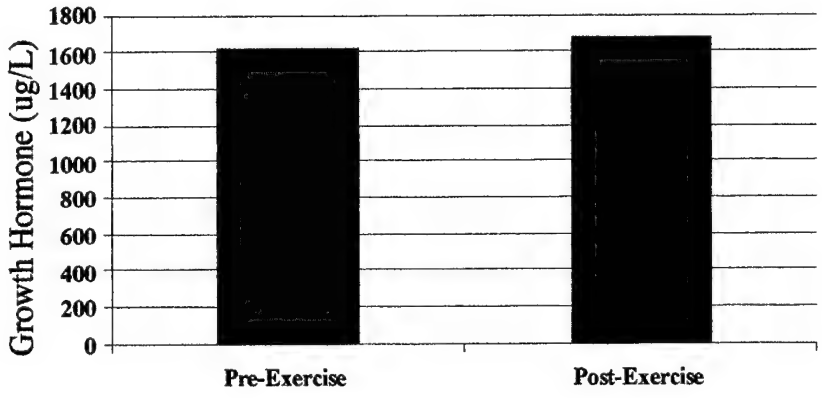


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Figure 30. Bioassay GH for exercise.

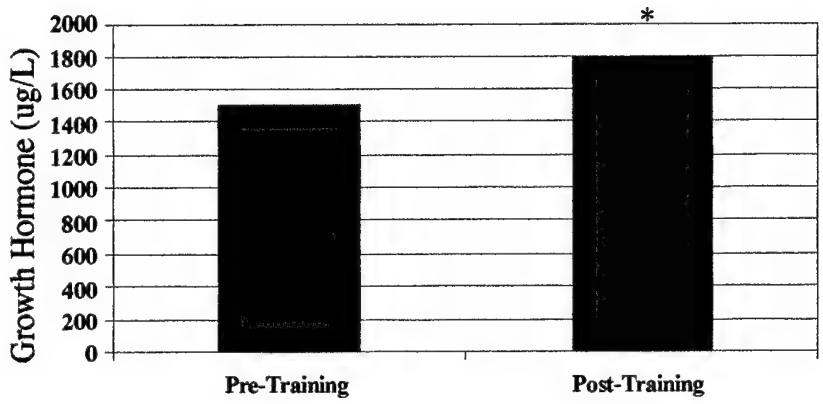

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Figure 31. The marginal means for training illustrating significant (* = P< 0.05) increases in BGH after 6 months of physical training.

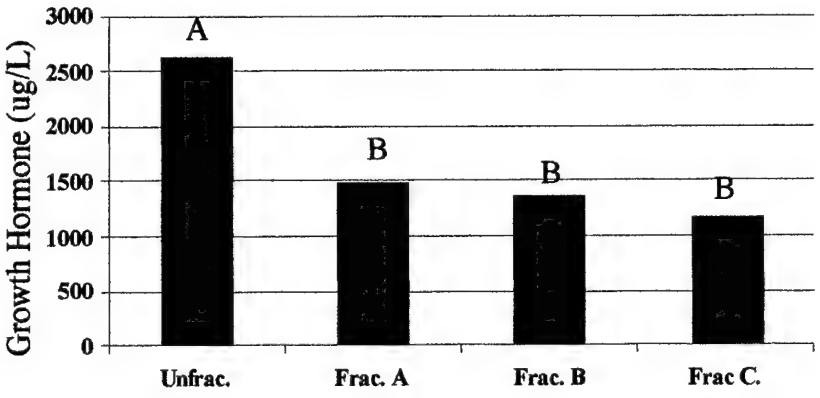

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Figure 32. This shows the BGH in each of the fractions. The unfractionated samples had higher ($p < 0.05$) concentrations than all 3 fractionated samples; all three fractionated samples exhibited similar bioactivity. A symbol different ($P < 0.05$) Bs.

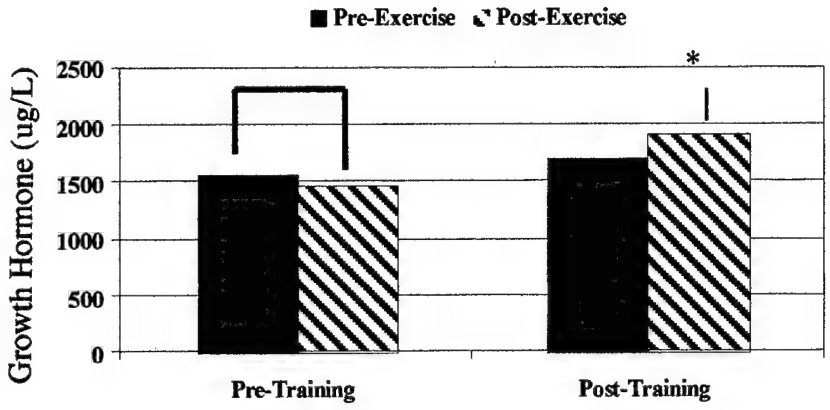

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Figure 33. Significant (*= P <0.05) interaction effects were noted for "training X exercise". After six months of training, post-exercise BGH was greater than the corresponding pre-training value.

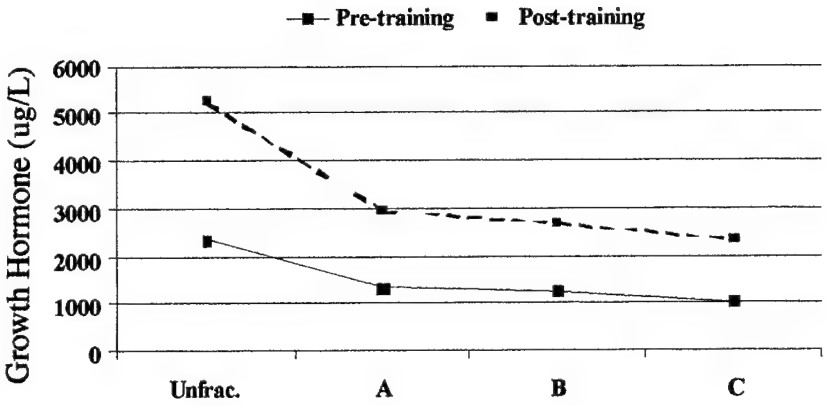

Figure 34. Illustration the "fraction X exercise" for BGH.

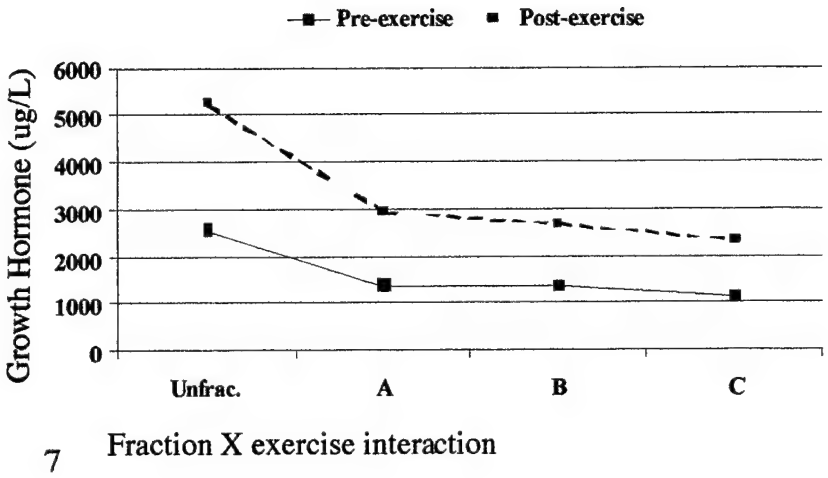

Figure 35. Illustrates "fraction X training" interactions for BGH

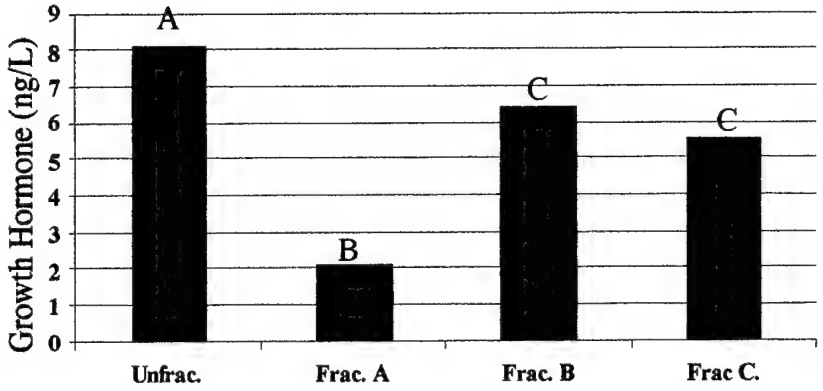

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Figure 36. This figure shows that the unfractionated sample had the highest immunoreactivity and that fraction A had lower immunoreactivity than fractions B and C. [Like symbols (top of bars ABC) represent no significant difference.]

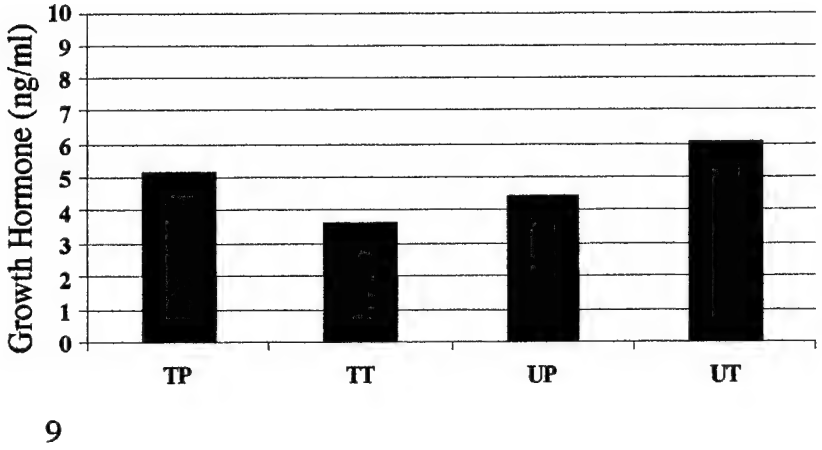

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Figure 37. The immunoreactivity among the training groups.

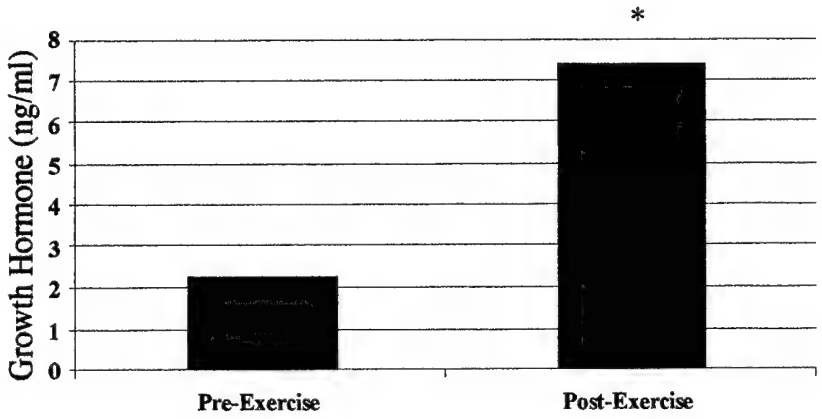

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Figure 38. The marginal means due to exercise.

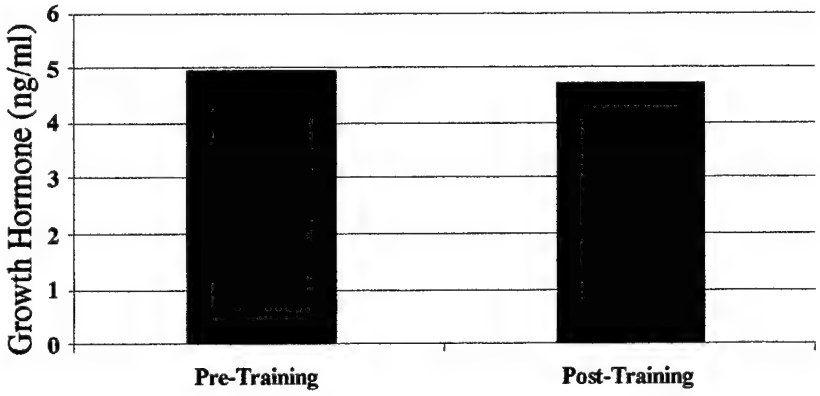

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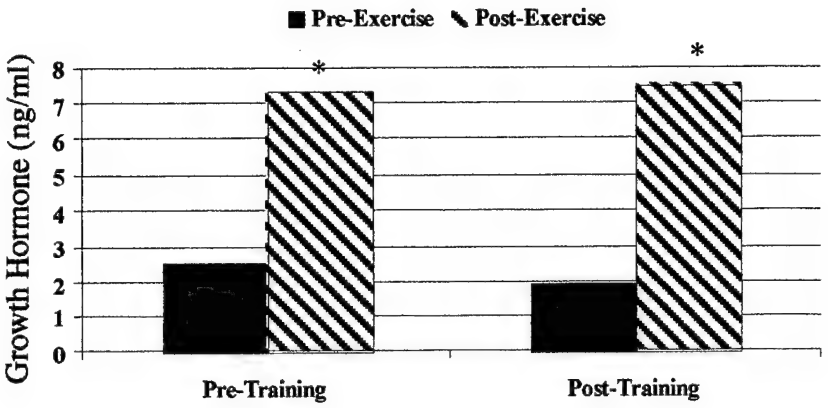
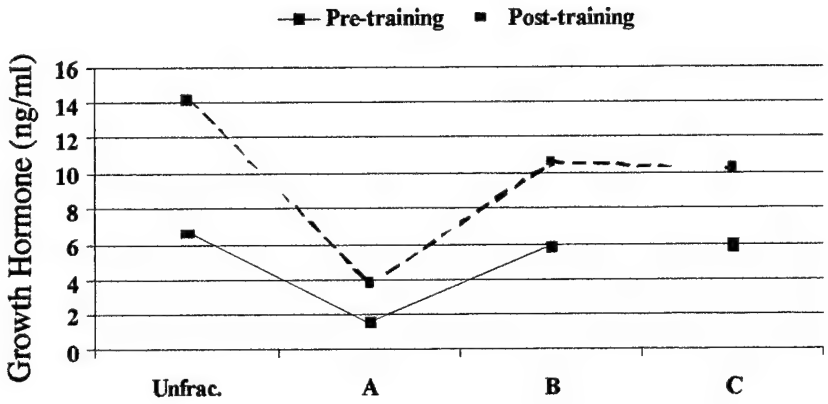
Figure 39. The marginal means due to training.



12

Figure 40. Shows the "training X exercise" interaction.



13

Figure 41. Shows the "fraction X training"

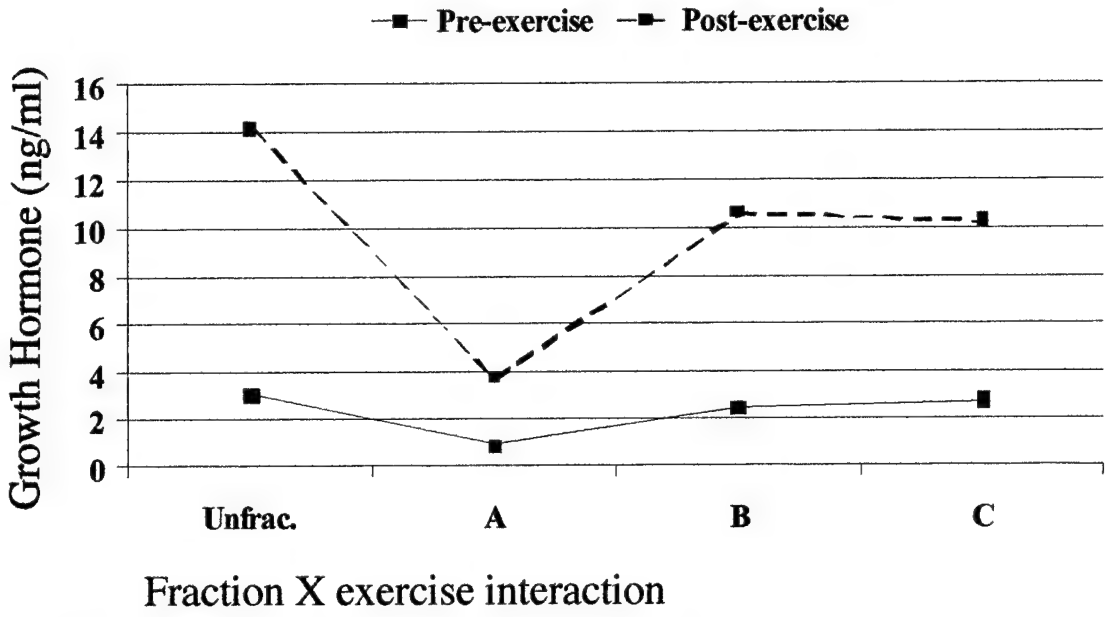


Figure 42. Shows the "fraction X exercise" interactions.

Growth Hormone

The changes in growth hormone were as expected with regards to the IGH where increases occurred with acute exercise. The lack of any changes over the training period remains unclear as other studies exmaining endurance training have seen a decrease in IGH responses. However, the lack of large changes in nutritional profiles, limited body fat reductions toward the norm in men (e.g., 16%), and a very reasonable endurance training program could all contribute to an explanation of limited change in IGH. Conversely, the observations on BGH remain novel and a subject for further research. The increase in the post-exercise BGH after 6 months of training is provacative in that the molecular variants or isoforms found in this type of GH are targeted at immune, bone and muscle cells for biological activity. The lack of exercise induced increases with acute exercise

remains unclear and could be a function of a single measurement missing the time course of changes for this response. The study of bioactive forms of GH with exercise training remains in the very embryonic stage of study in the field of exercise physiology. With the understanding that the typical IGH monomere having only limited interactions with many of the different tissues in the body, the importance of BGH and its newly found binding proteins remains an important area of study for future work. This investigation, opened the door into the first view of this physiological response to resistance exercise stress. No doubt it is more than just the 22 kD monomere that is affected by the development of adaptations related to heavy resistance training (e.g., increased muscle size and strength). Definitive answers as to the effects and mechanisms of bioactive versus immunoreactive growth hormones remain to be elucidated in future studies. This study shows that they are responsive in part and should be studied as a key component of metabolic anabolism in women's biological function in response to physical conditioning.

Immunological Variables

The cumulative effects to the immune system of repeated stresses from heavy resistance exercise over a period of many months are unknown. Based on research from other types of exercise (walking, running, cycling and swimming, low and high intensity, and from a few seconds to several hours in duration), it is clear that several components of the immune system respond dramatically to exercise. Particularly stressful exercise events, e.g. a marathon race, are associated with suppression of blood borne immune functions and increased incidence of upper respiratory tract infections. The effects of heavy resistance training on immune function have been largely ignored.

There is very little data available to determine whether individuals who participate in heavy resistance training programs should be concerned about potential modulations in immune function. However, there are several reasons to suspect that the demands of resistance training may affect immune function. First, high forces generated during weight lowering can induce microscopic tears within the active muscles, as evidenced by the delayed onset muscle soreness often experienced by individuals after resistance training. These tears elicit infiltration of neutrophils and macrophages, the production of cytokines and other inflammatory mediators, and ultimately the activation of anti-inflammatory processes. Cortisol is a potent anti-inflammatory mediator that helps to control inflammation. Cortisol is not selective in its down regulation of the immune system, and other immune functions not related to inflammation also are susceptible to its effects. Thus, individuals doing heavy resistance training are likely to expend

immune system resources in response to tissue injury. This expense, in conjunction with the suppressive influence of inflammatory control mechanisms, may lead to a broad down regulation of several immune parameters.

Conversely, resistance and other forms of exercise increase several growth and immunostimulatory factors. Growth hormone and IGF-1 increase in response to resistance exercise and have a stimulatory effect some components of the immune system. This influence would be more likely to have a positive effect on immune function. However, it is not known whether the up or down regulating influences of resistance training will be balanced, or whether one or the other will predominate and alter resting immune function and or the magnitude of the immune response to exercise. Because the immune system is responsible for protecting the individual from infectious illnesses, the influence of resistance training on immune function was assessed in this investigation.

Several immunological parameters were assessed in all subjects during the course of this investigation. The aim was to measure immune system responses under the following three training conditions: 1) the immediate response to an acute bout of resistance exercise before the training program, 2) chronic changes in resting immune status over the course of six months of training, and 3) the magnitude of the response to an acute bout of resistance exercise after zero, three and six months of resistance training.

Leukocyte complete blood count. The data for neutrophil (granulocyte), lymphocyte, and monocyte concentrations are given in Tables 7 through 10, respectively. For resting neutrophil count, there was a decrease ($P=0.016$) from 0

to 6 months, but no difference among the groups. Thus, the decrease over time was not associated with training. There was an increase ($P < 0.001$) in neutrophil concentration from pre- to post-exercise for all groups, and the magnitude of this increase was not influenced by training mode (no group by time interaction).

Resting lymphocyte concentration did not vary among groups or across training. Lymphocyte concentration increased in response to acute resistance exercise for all groups. The magnitude of this increase did not differ by group or across training.

Similarly to the lymphocyte concentration, resting monocyte concentration did not vary among groups or across training. Monocyte concentration increased in response to acute resistance exercise for all groups. The magnitude of this increase did not differ by group or across training. Thus, all three major classes of leukocytes increased in the circulation immediately after acute resistance exercise. However, six months of training, regardless of mode, had no apparent effect on resting cell concentrations or the magnitude of the exercise-induced response.

Table 7. Neutrophil concentration (neutrophils x $10^3 \cdot \mu l^{-1}$).

Group	Time	0 Months	3 Months	6 Months[a]
UP S-P	Pre	4.5 ± 1.3	4.5 ± 1.9	3.8 ± 0.9
	Post	5.7 ± 1.3[b]	6.6 ± 2.9[b]	5.4 ± 1.3[b]
UP H-S-E	Pre	4.5 ± 1.4	4.0 ± 1.3	3.9 ± 1.3
	Post	5.9 ± 1.6[b]	5.5 ± 2.7[b]	5.7 ± 2.3[b]

TOT S-P	Pre Post	4.0 ± 1.2 5.4 ± 1.8[b]	3.7 ± 1.3 5.0 ± 1.6[b]	3.8 ± 1.2 4.9 ± 1.4[b]
TOT H-S-E	Pre Post	4.7 ± 1.4 6.5 ± 1.8[b]	4.4 ± 1.4 5.6 ± 1.7[b]	4.5 ± 1.4 6.2 ± 2.0[b]
AER	Pre Post	5.1 ± 2.4 6.6 ± 2.9[b]	4.4 ± 2.2 6.5 ± 2.9[b]	4.2 ± 2.3 6.7 ± 3.5[b]
FIELD (	Pre Post	3.8 ± 0.9 5.4 ± 1.4[b]	3.5 ± 1.3 5.2 ± 1.9[b]	3.5 ± 1.1 5.3 ± 1.8[b]
CONTROL (n=6)	Pre Post	4.0 ± 0.7 4.4 ± 0.7[b]	3.9 ± 0.8 --	3.2 ± 0.7 --

[a] =P<0.05 compared to 0 and 3 months. [b] =P<0.05 compared to pre-exercise.

Table 8. Lymphocyte concentration (lymphocytes x $10^3 \cdot \mu l^{-1}$).

Group	Time	0 Months	3 Months	6 Months
UP S-P	Pre	2.4 ± 0.5	2.3 ± 0.4	2.4 ± 0.7
	Post	4.3 ± 0.8[b]	4.4 ± 0.9[b]	4.4 ± 1.1[b]
UP H-S-E	Pre	2.2 ± 0.7	2.2 ± 0.7	2.3 ± 0.5
	Post	4.0 ± 1.1[b]	3.7 ± 1.2[b]	4.1 ± 0.8[b]
TOT S-P	Pre	2.4 ± 0.7	2.5 ± 0.8	2.4 ± 0.6
	Post	3.7 ± 0.9[b]	4.1 ± 1.2[b]	3.7 ± 0.9[b]
TOT H-S-E	Pre	2.5 ± 1.1	2.6 ± 0.7	2.3 ± 0.8
	Post	4.1 ± 1.4[b]	4.3 ± 1.1[b]	3.9 ± 1.2[b]
AER	Pre	2.2 ± 0.4	2.2 ± 0.5	1.9 ± 0.5
	Post	3.9 ± 1.4[b]	4.4 ± 1.3[b]	4.0 ± 1.5[b]
FIELD	Pre	2.7 ± 1.0	2.6 ± 0.7	2.5 ± 0.7
	Post	4.0 ± 1.2[b]	4.2 ± 1.2[b]	4.1 ± 1.0[b]
CON	Pre	2.2 ± 0.5	2.1 ± 0.8	2.8 ± 1.0
(n = 6)	Post	2.1 ± 0.5	--	--

[b]$P<0.05$ compared to pre-exercise.

Table 9. Monocyte concentration (monocytes x $10^3 \cdot \mu l^{-1}$).

Group	Time	0 Months	3 Months	6 Months
UP S-P	Pre	0.4 ± 0.1	0.5 ± 0.5	0.5 ± 0.3
	Post	0.7 ± 0.3[b]	0.7 ± 0.5[b]	0.8 ± 0.3[b]
UP H-S-E	Pre	0.4 ± 0.2	0.5 ± 0.2	0.3 ± 0.1
	Post	0.6 ± 0.4[b]	0.7 ± 0.5[b]	1.5 ± 0.2[b]
TOT S-P	Pre	0.5 ± 0.2	0.5 ± 0.2	0.4 ± 0.2
	Post	0.6 ± 0.2[b]	0.7 ± 0.3[b]	0.6 ± 0.3[b]
TOT H-S-E	Pre	0.3 ± 0.2	0.4 ± 0.2	0.3 ± 0.1
	Post	0.5 ± 0.2[b]	0.6 ± 0.3[b]	0.5 ± 0.2[b]
AER	Pre	0.4 ± 0.2	0.4 ± 0.1	0.4 ± 0.2
	Post	0.6 ± 0.3[b]	0.6 ± 0.3[b]	0.8 ± 0.4[b]
FIELD	Pre	0.4 ± 0.1	0.4 ± 0.2	0.3 ± 0.1
	Post	0.6 ± 0.2[b]	0.6 ± 0.2[b]	0.5 ± 0.2[b]
CON	Pre	0.4 ± 0.1	0.3 ± 0.1	0.6 ± 0.7
(n = 6)	Post	--	--	--

[b]$P<0.05$ compared to pre-exercise.

Lymphocyte Surface Expression of Phenotypic and Functional Proteins

Table 10. Whole blood natural killer (NK) lymphocyte concentration (lymphocytes x $10^3 \cdot \mu l^{-1}$).

Group	Time	0 Months	3 Months[a]	6 Months
UP S-P	Pre	0.27 ± 0.19	0.32 ± 0.18	0.25 ± 0.17
	Post[b]	0.97 ± 0.53	1.11 ± 0.41	1.00 ± 0.48
UP H-S-E	Pre	0.25 ± 0.16	0.32 ± 0.23	0.19 ± 0.11
	Post[b]	0.90 ± 0.45	0.86 ± 0.35	0.90 ± 0.42
TOT S-P	Pre	0.34 ± 0.24	0.42 ± 0.20	0.22 ± 0.13
	Post[b]	0.96 ± 0.39	1.08 ± 0.39	0.79 ± 0.40
TOT H-S-E	Pre	0.34 ± 0.22	0.49 ± 0.31	0.27 ± 0.18
	Post[b]	1.12 ± 0.63	1.09 ± 0.51	0.94 ± 0.58
AER	Pre	0.29 ± 0.14	0.24 ± 0.13	0.26 ± 0.17
	Post[b]	0.93 ± 0.51	1.13 ± 0.56	0.95 ± 0.54
FIELD	Pre	0.33 ± 0.27	0.34 ± 0.19	0.33 ± 0.27
	Post[b]	0.86 ± 0.26	1.09 ± 0.52	0.97 ± 0.29
CON (N=6) (n = 7)	Pre	0.26 ± 0.17	0.21 ± 0.06	0.29 ± 0.16
	Post	--	--	--

[a]P<0.05 compared to 0 and 6 months.
[b]P<0.05 compared to pre-exercise.

For resting NK cell concentration, a significant group by training interaction was found. The resistance training groups all increased after 3 months of training and decreased to below pre-training levels after 6 months of training. The AER, FIELD, and CON groups did not change across training. There was a significant increase in NK cell concentration during the exercise. The magnitude of this increase was not affected by training mode or duration of training.

Table 11 Whole blood T lymphocyte concentration (lymphocytes x $10^3 \cdot \mu l^{-1}$).

Group	Time	0 Months	3 Months	6 Months[a]
UP S-P	Pre	1.80 ± 0.43	1.71 ± 0.37	1.75 ± 0.50
(n = 16)	Post	2.81 ± 0.66	2.95 ± 0.89	2.80 ± 0.80
UP H-S-E	Pre	1.63 ± 0.60	1.56 ± 0.57	1.70 ± 0.51
(n = 16)	Post	2.55 ± 0.85	2.42 ± 0.88	2.69 ± 0.70
TOT S-P	Pre	1.65 ± 0.43	1.86 ± 0.63	1.66 ± 0.50
(n = 18)	Post	2.25 ± 0.62	2.69 ± 0.87	2.25 ± 0.65
TOT H-S-E	Pre	1.75 ± 0.91	1.79 ± 0.62	1.63 ± 0.69
(n = 15)	Post	2.50 ± 1.06	2.72 ± 0.88	2.27 ± 0.96
AER	Pre	1.59 ± 0.32	1.53 ± 0.37	1.33 ± 0.37
(n = 9)	Post	2.50 ± 089	2.67 ± 0.83	2.45 ± 0.72
FIELD	Pre	2.12 ± 0.79	1.94 ± 0.58	1.74 ± 0.51
(n = 13)	Post	2.69 ± 1.03	2.70 ± 0.76	2.56 ± 0.79
CON	Pre	1.75 ± 0.35	1.73 ± 0.60	1.68 ± 0.67
(n = 7)	Post	--	--	--

[a]$P<0.05$ compared to 3 months.

For the resting samples, there is a significant group by time interaction. The AER and FIELD groups decrease over training while the other groups are reasonable consistent. The CON group increased from 3 to 6 months. There is an increase from pre- to post-exercise that is consistent across groups and training.

Table 12. Whole blood B lymphocyte concentration (lymphocytes x $10^3 \mu l^{-1}$).

Group	Time	0 Months	3 Months	6 Months
UP S-P	Pre	0.23 ± 0.10	0.19 ± 0.06	0.16 ± 0.06
	Post	0.32 ± 0.14	0.30 ± 0.11	0.21 ± 0.07
UP H-S-E	Pre	0.17 ± 0.09	0.17 ± 0.11	0.15 ± 0.08
	Post	0.24 ± 0.12	0.27 ± 0.17	0.25 ± 0.16
TOT S-P	Pre	0.20 ± 0.11	0.21 ± 0.08	0.22 ± 0.13
	Post	0.26 ± 0.14	0.32 ± 0.14	0.27 ± 0.19
TOT H-S-E	Pre	0.28 ± 0.14	0.25 ± 0.10	0.22 ± 0.11
	Post	0.37 ± 0.14	0.40 ± 0.31	0.31 ± 0.14
AER	Pre	0.15 ± 0.08	0.20 ± 0.07	0.21 ± 0.18
	Post	0.26 ± 0.16	0.37 ± 0.19	0.38 ± 0.31
FIELD	Pre	0.23 ± 0.14	0.23 ± 0.10	0.26 ± 0.14
	Post	0.31 ± 0.16	0.32 ± 0.15	0.34 ± 0.12
CON (n = 6)	Pre	0.24 ± 0.09	0.25 ± 0.06	0.34 ± 0.11
	Post	--	--	--

For resting B cell concentration, there is a significant group by training interaction. The resistance training groups either decline modestly or stay consistent. The AER, FIELD, and CON groups tended to increase as training progressed. There was a significant increase in B cell concentration during the resistance exercise. There was also a significant training by pre/post interaction. It appears that the magnitude of the increase from pre to post-exercise was greatest after 3 months of training.

Table 13 . The incorporation of tritiated thymidine in response to stimulation isolated PBMC with a sub-optimal dose of phytohemagglutinin-M (PHA Low). Values = mean ± SD counts per minute.

Group	Time	0 Months	3 Months[a]	6 Months
UP S-P	Pre	40,955 ± 33,756	25,162 ± 18,827	39,164 ± 33,211
	Post	43,031 ± 29,359	27,410 ± 20,400	43,705 ± 37,626
UP H-S-E	Pre	52,687 ± 33,374	36,292 ± 28,322	50,159 ± 42,233
	Post	56,129 ± 34,048	35,174 ± 27,679	46,419 ± 42,781
TOT S-P	Pre	56,095 ± 41,549	39,013 ± 27,117	43,048 ± 29,671
	Post	54,611 ± 40,327	39,118 ± 26,544	46,665 ± 31,777
TOT H-S-E	Pre	54,947 ± 37,818	39,192 ± 35,460	39,364 ± 27,344
	Post	57,520 ± 41,860	45,284 ± 34,902	41,213 ± 30,362
AER	Pre	27,715 ± 25,768	107,634 ± 63,510	37,166 ± 21,840
	Post	34,078 ± 21,532	124,848 ± 63,981	45,692 ± 26,066
FIELD	Pre	53,251 ± 61,819	92,248 ± 41,633	42,606 ± 22,052
	Post	72,993 ± 63,139	101,626 ± 56,190	60,467 ± 23,106
CON[c] (n = 6)	Pre	39,101 ± 43,582	73,782 ± 46,878	68,540 ± 47,962
	Post	--	--	--

[a]P<0.05 compared to 0 and 6 months.
[c]P<0.05 compared to UP S-P.

Main effects of group, training and pre/post are significant and the group x training and the group x pre/post interactions are significant. All groups start at about the same place and then the AER, FIELD, and CON groups go up at 3 months and back down at 6 months. The post-exercise means are higher than those for pre-exercise.

Table 14. The incorporation of tritiated thymidine in response to stimulation isolated PBMC with an optimal dose of phytohemagglutinin-M (PHA High). Values = mean ± SD counts per minute.

Group	Time	0 Months	3 Months	6 Months
UP S-P	Pre	57,799 ± 36,164	71,531 ± 24,590	84,863 ± 35,648
	Post	59,194 ± 36,645	64,780 ± 32,528	83,694 ± 37,979
UP H-S-E	Pre	69,810 ± 32,224	88,235 ± 22,040	101,905 ± 43,802
	Post	69,163 ± 28,552	85,270 ± 21,774	100,262 ± 42,243
TOT S-P	Pre	67,811 ± 39,147	75,973 ± 32,042	85,703 ± 34,934
	Post	74,989 ± 41,875	71,528 ± 29,320	87,135 ± 33,744
TOT H-S-E	Pre	74,605 ± 38,653	77,692 ± 42,783	74,037 ± 33,082
	Post	75,199 ± 40,734	64,417 ± 39,536	72,689 ± 31,710
AER	Pre	190,725 ± 85,081	166,171 ± 89,074	88,565 ± 32,744
	Post	185,347 ± 54,611	178,795 ± 77,504	87,199 ± 21,855
FIELD	Pre	228,012 ± 83,491	183,529 ± 107,298	106,325 ± 38,125
	Post	195,757 ± 89,258	163,828 ± 100,549	119,900 ± 37,529
CON (n = 6)	Pre	90,450 ± 57,080	130,739 ± 76,883	132,930 ± 73,824
	Post	--	--	--

For the resting measure only, there is a significant group by training interaction. The AER and FIELD groups are high at 0 months and decrease toward the rest of the groups at 3 and 6 months. All other groups appear to be gradually increasing from 0 to 6 months. The control group is between the strength training groups and the FIELD and AER groups. There is no effect of the acute exercise on the response..

Table 15. The incorporation of tritiated thymidine in response to stimulation isolated PBMC with a sub-optimal dose of Concanavalin A (Con A Low). Values = mean ± SD counts per minute.

Group	Time	0 Months	3 Months	6 Months
UP S-P	Pre	35,519 ± 17,936	40,723 ± 12286	48,363 ± 18,051
	Post	35,854 ± 16,374	37,196 ± 10743	48,947 ± 21,831
UP H-S-E	Pre	44,912 ± 22,065	45,717 ± 8325	59,431 ± 21,696
	Post	48,257 ± 21,923	43,423 ± 10422	55,759 ± 22,041
TOT S-P	Pre	43,311 ± 23,410	38,752 ± 13139	44,854 ± 17,204
	Post	46,193 ± 18,605	37,822 ± 12026	44,689 ± 16,088
TOT H-S-E	Pre	47,581 ± 19,096	41,956 ± 9320	42,828 ± 19,633
	Post	44,452 ± 17,897	38,858 ± 13263	38,299 ± 18,835
AER	Pre	112,926 ± 17,717	109,082 ± 24280	48,722 ± 13,321
	Post	109,082 ± 20,976	100,144 ± 23041	55,028 ± 8,290
FIELD	Pre	109,296 ± 24,185	90,044 ± 30284	53,141 ± 15,219
	Post	105,287 ± 32,264	85,185 ± 22962	60,332 ± 15,331
CON (n = 6)	Pre	47,779 ± 22,681	61,416 ± 35072	58,946 ± 26,750
	Post	--	--	--

For the resting measurement alone, AER and FIELD different from all others, significant interaction (group x training) in which these 2 groups start much higher than all other groups and decrease over the course of the training. At 6 months, they are at the level that all other groups were at all along. There is no change pre to post-exercise.

Table 16. The incorporation of tritiated thymidine in response to stimulation isolated PBMC with an optimal dose of Concanavalin A (Con A High). Values = mean ± SD counts per minute.

Group	Time	0 Months	3 Months	6 Months
UP S-P	Pre	44,574 ± 15,087	46,808 ± 18,768	51,126 ± 29,118
	Post	40,501 ± 15,123	40,297 ± 17,693	47,788 ± 24,287
UP H-S-E	Pre	45,308 ± 23,867	52,043 ± 17,758	69,983 ± 26,732
	Post	46,428 ± 24,846	47,897 ± 15,393	64,748 ± 26,033
TOT S-P	Pre	48,229 ± 18,820	49,573 ± 14,600	55,418 ± 23,044
	Post	45,722 ± 21,880	47,996 ± 13,339	53,228 ± 16,141
TOT H-S-E	Pre	54,514 ± 18,246	54,195 ± 6,816	92,454 ± 150,488
	Post	49,529 ± 17,889	45,124 ± 16,219	45,587 ± 26,821
AER	Pre	131,843 ± 33,691	101,359 ± 44,329	56,128 ± 10,063
	Post	132,296 ± 42,701	98,039 ± 40,710	63,236 ± 15,077
FIELD	Pre	125,982 ± 19,063	110,609 ± 31,599	72,312 ± 17,985
	Post	126,052 ± 29,106	108,322 ± 34,464	76,159 ± 15,435
CON	Pre	84,631 ± 40,258	78,667 ± 32,258	78,464 ± 60,120
	Post	--	--	--

AER and FIELD (and to a lesser extent, the CONTROL group) are different from all others. There is a significant interaction (group x training) in which these 2 groups start much higher than all other groups and decrease over the course of the training. At 6 months, they are at the level that all other groups were at all along. The main effect of training is not significant, but, as described, the group by training interaction is significant.

Table 17. The incorporation of tritiated thymidine in response to stimulation of isolated PBMC with a sub-optimal dose of pokeweed mitogen (PWM Low). Values = mean ± SD counts per minute.

Group	Time	0 Months	3 Months	6 Months
UP S-P	Pre	24,288 ± 14,368	30,599 ± 12,857	28,137 ± 19,748
	Post	23,855 ± 12,060	19,463 ± 10,208	23,556 ± 19,897
UP H-S-E	Pre	32,847 ± 17,613	34,065 ± 14,797	30,011 ± 19,507
	Post	28,580 ± 16,386	26,856 ± 12,629	26,882 ± 19,034
TOT S-P	Pre	36,518 ± 17,479	32,879 ± 15,594	20,699 ± 18,897
	Post	37,120 ± 22,612	29,260 ± 18,817	19,339 ± 16,441
TOT H-S-E	Pre	33,150 ± 19,487	34,848 ± 12,799	30,202 ± 20,877
	Post	30,099 ± 14,862	25,336 ± 9,926	25,470 ± 18,698
AER	Pre	96,035 ± 23,180	71,904 ± 25,144	44,606 ± 14,097
	Post	76,529 ± 20,137	63,712 ± 13,900	45,869 ± 15,124
FIELD	Pre	100,011 ± 22,294	73,080 ± 18,827	50,461 ± 10,624
	Post	87,692 ± 20,955	60,276 ± 18,553	43,736 ± 12,520
CON (n = 5)	Pre	64,392 ± 33,392	62,780 ± 23,881	63,609 ± 20,598
	Post	--	--	--

AER and FIELD (and to a lesser extent, the CONTROL group) different from all others, significant interaction (group x training) in which these 2 groups start much higher than all other groups and decrease over the course of the training. At 6 months, they are at the level that all other groups were at all along. The main effect of training is not significant. However, the main effect of pre/post was significant, with the post-exercise measure being lower compared to pre-exercise.

Table 18. The incorporation of tritiated thymidine in response to stimulation of isolated PBMC with an optimal dose of pokeweed mitogen (PWM High). Values = mean ± SD counts per minute.

Group	Time	0 Months	3 Months[a]	6 Months[a]
UP S-P	Pre	21,210 ± 10,175	29,111 ± 13,107	25,735 ± 11,475
	Post	19,839 ± 11,607	17,030 ± 8,894	22,916 ± 16,418
UP H-S-E	Pre	32,104 ± 20,789	33,685 ± 9,509	39,948 ± 15,338
	Post	26,181 ± 13,248	25,097 ± 7,344	32,450 ± 16,811
TOT S-P	Pre	33,030 ± 17,700	31,624 ± 11,574	25,240 ± 13,569
	Post	26,027 ± 12,896	19,980 ± 8,444	26,842 ± 12,116
TOT H-S-E	Pre	29,837 ± 17,127	32,755 ± 9,336	30,880 ± 15,381
	Post	24,421 ± 14,440	22,353 ± 9,013	29,921 ± 15,217
AER	Pre	82,873 ± 25,862	62,863 ± 23,997	40,922 ± 12,812
	Post	58,135 ± 19,845	49,029 ± 12,874	37,371 ± 15,736
FIELD	Pre	88,653 ± 25,698	64,293 ± 19,806	47,310 ± 10,669
	Post	66,802 ± 23,859	48,383 ± 17,458	33,788 ± 13,872
CON (n = 6)	Pre	61,410 ± 19,081	67,786 ± 28,734	61,239 ± 10,537
	Post	--	--	--

[a]$P<0.05$ compared to 0 Months.

Same as for PWM Low except that the main effect for training is significant with 3 and 6 months lower than 0 months.

Table 19. The incorporation of tritiated thymidine in response to stimulation isolated PBMC with a sub-optimal dose of Staphylococcus *aurieus* Cowans (Sac Low). Values = mean ± SD counts per minute.

Group	Time	0 Months	3 Months	6 Months
UP S-P	Pre	7,513 ± 5,543	7,478 ± 4,270	9,454 ± 8,999
	Post	7,101 ± 6,108	6,267 ± 2,397	7,992 ± 7,588
UP H-S-E	Pre	7,734 ± 7,520	9,331 ± 4,917	8,628 ± 7,935
	Post	6,125 ± 4,431	8,286 ± 6,672	8,537 ± 6,966
TOT S-P	Pre	7,964 ± 5,475	8,896 ± 5,516	7,885 ± 5,805
	Post	8,222 ± 7,812	6,201 ± 3,138	7,297 ± 5,048
TOT H-S-E	Pre	6,369 ± 3,581	10,048 ± 4,128	8,337 ± 7,967
	Post	6,051 ± 4,426	6,903 ± 2,846	6,602 ± 6,221
AER	Pre	18,860 ± 11,448	12,371 ± 7,424	6,565 ± 4,305
	Post	15,811 ± 6,435	14,777 ± 5,423	8,484 ± 4,592
FIELD	Pre	17,309 ± 7,918	16,628 ± 12,698	8,053 ± 3,710
	Post	15,067 ± 5,538	12,034 ± 9,621	8,981 ± 3,952
CON	Pre	13,397 ± 4,658	14,208 ± 9,267	10,409 ± 7,010
(n = 6)	Post	--	--	--

Table 20. The incorporation of tritiated thymidine in response to stimulation isolated PBMC with a sub-optimal dose of Staphylococcus *aurieus* Cowans (Sac Low). Values = mean ± SD counts per minute.

Group	Time	0 Months	3 Months	6 Months
UP S-P	Pre	8,177 ± 5,511	7,018 ± 5,214	8,080 ± 6,875
	Post	6,881 ± 2,992	5,127 ± 3,584	6,543 ± 4,930
UP H-S-E	Pre	6,292 ± 4,742	7,726 ± 4,030	7,993 ± 5,779
	Post	5,117 ± 3,729	8,913 ± 6,985	7,552 ± 5,001
TOT S-P	Pre	9,091 ± 7,905	6,839 ± 4,533	8,165 ± 4,982
	Post	7,071 ± 4,337	5,377 ± 3,523	6,808 ± 3,692
TOT H-S-E	Pre	5,367 ± 3,245	9,167 ± 4,534	6,965 ± 4,504
	Post	5,161 ± 3,394	6,748 ± 4,867	5,378 ± 3,385
AER	Pre	16,080 ± 7,123	17,464 ± 11,182	10,180 ± 3,526
	Post	14,001 ± 6,123	14,738 ± 7,573	10,616 ± 3,329
FIELD	Pre	17,153 ± 6,809	15,765 ± 7,349	13,010 ± 8,080
	Post	15,214 ± 6,912	12,706 ± 6,158	11,673 ± 7,370
CON (n = 6)	Pre	16,842 ± 8,356	15,250 ± 10,171	14,357 ± 7,503
	Post	--	--	--

For the resting measure, there are differences among groups, but not across training. The AER, FIELD, and CON groups are higher than all other groups. Including the post-exercise measure, there is a significant group by training interaction where the control group is heading up from 0 to 6 months, the AER and FIELD groups are declining from 0 to 6 months, and the remaining groups are reasonable consistent over time.

The assessment of immunological parameters yielded a number of findings. As the following list suggests, resistance training induced some changes that were not apparent in the AER, FIELD, or CON groups, while other changes measured seem to reflect seasonal variation:

Acute effects of resistance exercise before training (pre- vs. post-exercise for the 6x10 RM squat exercise):

1) Neutrophils, lymphocytes and monocytes increased ($P<0.001$) by 32, 63, and 50%, respectively.

2) All of the lymphocyte subsets increased ($P<0.001$). Natural killer, T cytotoxic, B, and T helper lymphocytes increased by 220, 60, 38, and 24%, respectively.

3) Four mitogens were used to stimulate lymphocyte proliferation, each at a sub-optimal (Low) and an optimal (High) concentration. There was a decrease in lymphocyte proliferation (incorporation of tritiated thymidine) for Low and High concentrations of pokeweed mitogen (PWM) and staphylococcus *aurieus* Cowans (SAC). The range for this decrease was from 11 to 20%. These two mitogens, PWM and SAC, stimulate both T and B lymphocytes to proliferate. There was no change pre- to post-exercise for phytohemagglutin-M (PHA) and concanavalin-A (ConA). The non-responsive mitogens, PHA and ConA, stimulate proliferation only in T lymphocytes.

Effect of training on resting (pre-exercise) immune parameters:

1) The concentration of neutrophils was lower ($P<0.05$) after 6 months of training compared to 0 and 3 months of training. However, this decrease was measured in the CON group as well as the exercise training groups, suggesting that this change was not a function of exercise training. Lymphocyte and monocyte concentrations did not change.

2) There were a number of significant group by training interactions ($P<0.05$) amongst the lymphocyte subset concentrations. The AER, FIELD, and CON groups had small decreases or no change in NK cell concentration, while all of the resistance training groups had increased NK lymphocyte concentrations after 3 months of training compared to 0 and 6 months. For T cytotoxic, T helper, and B lymphocytes, the CON group increased in concentration across the training period,

while the remaining groups stayed about the same (resistance training groups) or tended to decrease (AER and FIELD groups) across training.

3) With the exception of the AER and FIELD groups, lymphocyte proliferation responses across training were consistent. The AER and FIELD groups had much higher pre-training prolifereation responses than the other groups and decreased across the training period. However, all of the groups had similar responses after six months of training.

Effect of training on the magnitude of the response to acute resistance exercise:

1) The magnitude of the increase in granulocytes, lymphocytes and monocytes following the 6x10 RM squat test was not influenced by training for any of the groups.

2) The magnitude of the increase in NK and T cytotoxic lymphocytes after acute exercise was not affected by training for any of the groups. There was a significant training by pre- to post-exercise interaction ($P<0.05$) for T helper and B lymphocytes. The magnitude of the pre- to post-exercise increase was greater as training progressed. T helper and B lymphocytes increased by 45 and 40% after three and six months of training compared to 38 and 24% before training, respectively.

3) There were no significant changes in the magnitude of the change in the proliferation response following acute resistance exercise.

Summary and Conclusions

• Increases in endurance performance can be achieved with as little as 20 to 25 minutes of endurance training in the "training zone" after a resistance exercise workout.

• Most of the initial training adaptations in muscular strength, size, endocrine function, and immune cell changes can be seen with just three months of training.

• Training response are very specific to the type of program used, the movements trained, and the way exercises are performed in the training session (e.g., slow versus explosive). It appears that a periodized resistance training program that periodizes resistances from 8 RM and under and performs exercises in an explosive manner is most effective in eliciting gains in all fitness variables and seeing continued improvements in many variable with long term training in women. It might be hypothesized that the addition of a plyometric training program would futher enhance this basic resistance training program.

• An aggressive field training program utilizing explosive plyometrics and partner exercises appears to be effective in making gains in many variables and would be effective as a maintenance type of training program when equipment is limited.

• Effective training can allow for women to make significant gains on the typical man in physical performance. This was most striking in the load carriage capabilities which equal the men's capabilities

• Aerobic training alone is not effective in making gains in any of the military preformance tasks.

• Resistance training along with a basic endurance training program can effectively be used to enhance physical performance in military tasks without any direct practice of the task (e.g., box lift, ruck sack carriage) and this may in some cases reduce the exposure of the soldier to acute tramatic or overuse injuries with the performance of such tasks (e.g., load carriage) in a military training profile.

• Women's health appears to benefit from the participation in a resistance training program as muscle quality, performance, hormone function, immune function all are enhanced with training.

• The development of upper body size and strength in women plays a major role in physical performance in women and explains the major gains made in such military tasks as load carriage and box lifts. Historically, weakness in the upper body in women has been seen a major focus of a training program. Our data support the concept that the development of the upper body in women is crucial for optimal physical performance.

• Diffferent from other studies which posture neural changes as the primary mediator of force production abilities in women, the program designs used in this study resulted in direct data from MRI scans which indicate that women's thigh and arm muscles are very responsive to resistance training in the first three months of training. Women are capable of demonstrating a very dramatic whole muscle hypertrophic response which probably mediates much of the physical performance changes.

• This study demonstrated that despite the alterations in hypertrophy of muscle and strength and power changes with resistance training, fears about drastic changes in body size and a "big muscle" look were not realized by typical women. In addition, the and more leaner look with greater performance capabilities was found to be a positive outcome of the program.

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APPENDIX A

ABSTRACTS

355 PREDICTION OF REPETITIVE LIFTING ABILITY IN UNTRAINED WOMEN FROM MUSCULAR STRENGTH AND ENDURANCE

S. Meth, B.C. Nindl, L.A. Gotshalk, C.C. Loebel, S.A. Mazzetti, S.J. Fleck, R.U. Newton and W.J. Kraemer, FACSM, Ctr for Sports Med, Dept of Kines, and Noll Physio Research Ctr, Penn State University, University Park, PA (Sponsor:W.J. Kraemer, FACSM)

The relationship between characteristics of muscular performance (e.g. size, strength, power, endurance) and occupational tasks has not been clearly defined. This study assessed the physical performance of 47 untrained women (22 ± 3 yr; 165 ± 6 cm; 62 ± 8 kg; 25 ± 5 %BF) and identified via multiple regression analysis the best predictors of a repetitive lifting test (RLT). The RLT consisted of the maximum number of boxes (20.45 kg) that could be lifted from the floor to a height of 132 cm within a 10 min period (subjects were required to move between two boxes 2.4 m apart between lifts). Independent variables (IVs) included weight (wt), height (ht), MRI assessed arm and leg cross-sectional area, muscular strength 1RMs (bench press, squat, high pull, boxlift), upper and lower body explosive power (mechanical power determined from bench press throws and jump squats), muscular endurance (# of push-ups in 2 min and # of squat repetitions at a controlled rate with a 45 kg load) and aerobic capacity assessed from a 2 mile run (2MR in secs). The mean ±SD (range) for the RLT was : 92±25(20-159). For all IVs (excluding the 2MR) the following equation was generated : RLT (#) = 2.4(1RM boxlift in kg) + 0.70 (# of push-ups in 2 min) + 0.94 (Ht) - 146 [R= 0.83; SEE = 15; p≤0.05]. When 2MR was included, the equation was: RLT (#) = 2.9(1RM boxlift in kg) - 0.05 (2MR in secs) + 73 [R = 0.83; SEE = 14; p≤0.05]. Because the 1RM boxlift correlated higher than any of the other variables (r = 0.74) with RLT and entered into both equations, these results illustrate the importance of task-specific strength for predicting successful job performance. Also, the predictive value of a measure of aerobic capacity for RLT suggests that women can also benefit from endurance training for repetitive occupational tasks requiring total body strength and local muscular and aerobic endurance.

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937 POWER AND STRENGTH IN WOMEN: ADAPTATIONS FOLLOWING SIX MONTHS OF RESISTANCE TRAINING

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This study determined the effects of a periodized, total body strength/power (TBSP: 3-8 repetitions for 3 sets each of 8 exercises performed explosively, 120 sec rest between sets) and a total body strength/hypertrophy (TBSH: 8-12 repetitions for 3 sets each of 8 exercises, 45-90 sec rest between sets) training on power and strength in women. Thirty-six untrained women (23±4 yr., 165±7 cm, 63±8 kg) were randomly placed into TBSP (n=17) or TBSH (n=19) groups and trained 3 days/wk for 6 months. The women were tested before training (T1), after 3 months (T2), and after 6 months (T3) in 1-RM barbell squats, high pulls, and 30% of 1-RM jump squat power (all on a Plyometric Power System).

Variable	Group	T1 (± SD)	T2 (± SD)	Δ%	T3 (± SD)	Δ%	Δ% Total
1-RM Sq (kg)	TBSP	53 ± 12	65± 11	22.6	73 ±10	12.3	37.7
	TBSH	52 ± 11	63 ± 12	21.2	70 ± 14	11.1	34.6
1-RM HP (kg)	TBSP	34 ± 7	39 ± 7	14.7	41 ± 6	5.1	20.6
	TBSH	32 ± 5	34 ± 6	6.3	35 ± 6	2.9	9.4
Peak Pwr (W)	TBSP	1650 ± 372	1833 ± 370	11.1	1952 ± 406	6.5	18.3
	TBSH	1699 ± 250	1807 ± 278	5.98	1838 ± 259	1.7	8.2

An ANOVA with repeated measures indicated significant ($p \leq 0.05$) training effects for both groups in all variables. The TBSP group showed greater gains in the high pull and power output than did the TBSH group, yet both groups improved equally in the squat. Finally, this study demonstrated that, over six months, women can dramatically improve their power and strength with a periodized resistance training program, dependent on the specificity of the program.

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923 CONTRIBUTION OF UPPER BODY TRAINING ON TOTAL BODY STRENGTH AND POWER IN YOUNG WOMEN

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The purpose of this investigation was to determine the contribution of upper body strength training to total body strength/power perfonnance.. We examined the hypothesis that periodized upper body resistance training would aid in the increase in lower body power and strength in previously untrained young. 15 women (T) (baseline characteristics: 23 ± 2 yr, 164 ± 1 cm, 65 ± 0 kg, 24 ± 9 % BF) trained for 3 months in a periodized resistance total body program designed for gains in strength and power while 17 women (U)) (baseline characteristics: 22 ± 6 yr, 165 ± 2 cm, 64 ± 4 kg, 25 ± 4 % BF) participated in a similar program but with no lower body resistance training. All women were tested pre- and post-training for strength (1-RM squat [SQ], bilateral isometric leg extension [LX]), explosive power (peak watts generated during a jump squat at 30% of 1-RM SQ [JSQ]; and fat- and bone-free thigh muscle cross sectional area (assessed via magnetic resonance imaging [MSCA]). Results indicated that the T group made significant gains in all performance tests and MSCA, while the U group improved significantly only in the SQ, with no change of MCSA. The fact that the U group increased in the SQ but not the LX may be due in part to the strengthening of the shoulder girdle and torso which aided in the carriage and support of the bar during the 1-RM performance. Despite the fact that the prime movements tested by these lifts are of the lower body, the synergistic roles of the shoulder girdle and torso during the SQ play an important role throughout the eccentric and concentric phases of the lift. These data demonstrate that the upper body contribution to strength and power development is related to the added structural support for the load during maximal slow velocity 1-RM squat movements.

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994 DECREASED LYMPHOCYTE PROLIFERATION IN RESPONSE TO MITOGENIC AND ANTIGENIC STIMULATION DURING RESISTANCE TRAINING

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While the exercise stress during power resistance training can be tremendous, this type of training is seldom considered when evaluating the effects of exercise on the immune system. The purpose of this investigation was to determine whether the proliferative response of lymphocytes was affected by progressive, power, resistance training. Female subjects (n= 9) performed 3 power-based resistance training sessions per week. Resting blood samples were collected from training subjects and seasonally matched controls (n=3) at 0, 3, and 6 months. Peripheral blood mononuclear cells were isolated and cultured with several mitogens (phytohemagglutinin (PHA), Concanavalin A (Con A), and pokeweed mitogen PWM), a superantigen (*staphylococcus a.* cowans (Sac)), and a recall antigen (tetanus toxoid). Proliferation of stimulated lymphocytes was quantitated via the incorporation of tritiated thymidine. While lymphocyte proliferation in seasonally matched control subjects tended to increase over the three sampling periods, proliferation in the training group decreased. This difference was significant for a high concentration of Con A (group, P<0.01), low and high concentrations of PWM (group P<0.01 and group x time P<0.05, respectively), and low and high concentrations of Sac (group P<0.01 and P<0.05, respectively). For example, the response to Con A went from (mean ± SD x 10^3) 58.6 ± 17.1 to 49.6 ± 10.1 to 48.2 ± 11.6 cpm in the training group, and from 67.9 ± 16.9 to 69.6 ± 26.8 to 88.2 ± 30.8 cpm in the control group at 0, 3, and 6 months, respectively. These data suggest that the power resistance training was associated with a decrease in the proliferation responses of peripheral blood lymphocytes.

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924 THE DEVELOPMENT OF UPPER BODY PERFORMANCE IN WOMEN AFTER DIFFERENTIAL RESISTANCE TRAINING PROGRAMS

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The development for upper body performance in women is not well studied. It is thought that the use of loads ranging between 80-95% 1RM with longer (i.e. >2 min) rest periods performed in an "explosive type" manner are required to optimally train the neuromuscular system for the attainment of maximal force and power production. To test this hypothesis, 35 untrained women (23±4 yrs; 165±7 cm ; 63±8 kg) were randomly placed into either a total body strength power (TBSP, n=15) or a total body strength hypertrophy (TBSH, n=20) group. Both groups underwent periodized training 3x/wk for 12 wks: The TBSP group performed sets with loads at 80-95%1RM; reps ranging from 3-8 with 2 min rest period between sets; the TBSH group performed sets with loads at 60-75%1RM; reps ranging from 8-12 and 45-90 sec rest between sets. Bench press 1RM and peak power, rate of force development, and peak force was assessed via loaded bench throws (30% BP 1RM) with the aid of the Plyometric Power System pre and post training. Significant ($p \leq 0.05$) training effects were seen for all variables .

Variables	Group	Pre Values (±SD)	Post (± SD)	% Δ
PEAK POWER (w)	TBSP	163.9±74	203.4± 79.4	24
	TBSH	154.3±45.7	192.7 ± 57.6	23
RFD (N/s)	TBSP	280.1± 133	443.5±205.7	58
	TBSH	333.9± 2.9	381.4±175.5	14
FORCE (N)	TBSP	143.7± 48.9	185.8± 54.5	29
	TBSH	147.5± 54.4	174± 53.2	18
1RM BP (Kg)	TBSP	33.1± 8.4	40.8±10.1	23
	TBSH	32.2± 8.3	37.20± 8.4	15

These data demonstrate that women can experience gains in upper body strength, power, force and rate of force development within 12 weeks. However, 12 weeks is not long enough to observe differences in performance outcomes in delineated programs. *DOD US Army DAMD 17-95-5069*

1633 UPPER BODY RESISTANCE TRAINING IN WOMEN INCREASES ARM MUSCLE CROSS-SECTIONAL AREA BY A 20% AVERAGE

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This study determined the effects of 6 months of supervised, periodized upper body resistance training on women's upper body muscle cross-sectional area (MCSA). Subjects were placed into one of two groups: strength/power (S/P, n = 21) or strength/hypertrophy (S/H, n = 19). The groups were delineated by the repetitions and rest intervals between sets. Magnetic resonance imaging assessed the MCSAs of the singular muscles (i.e. biceps brachii, brachialis, and triceps brachii) of the upper arm at 3 points throughout training (pre (T1), mid (T2), and post (T3). An ANOVA with repeated measures revealed significant training effects for total and singular MCSAs (T1<T2<T3), with the exception of the brachialis. No group effects were revealed. * p ≤ 0.05 different from previous timepoint

Training Group	Total MCSA	Biceps Brachii MCSA	Brachialis MCSA	Triceps MCSA
S/P				
T1	32.0±3.8	7.7±1.0	4.3±0.8	19.5±2.8
T2	35.7±4.7*	8.5±1.4*	4.7±.08*	21.5±3.1*
T3	38.4±4.4*	9.1±1.3*	4.7±.6	23.4±2.8*
T1 to T3 %Δ	*20.4±8.7*	*17.9±13.2*	*12.5±15.1*	*20.3±16.4*
S/H				
T1	32.3±5.3	7.8±1.7	4.9±.9	19.7±3.4
T2	36.6±5.8*	8.5±2.0*	5.2±.9*	22.2±3.6*
T3	38.5±7.5*	9.1±2.3*	5.3±1.1	23.2±4.5*
T1 to T3 %Δ	*19.0±10.3*	*16.4±11.7*	*8.1±13.0*	*18.0±10.5*

%Δs for singular MCSAs ranged from 8 to 20%. Total upper arm MSCA hypertrophied by 20%. This study firmly establishes that with optimally designed resistance training, women can exhibit *impressive* hypertrophy in upper body muscle throughout 6 months of training. *DOD US Army DAMD 17-95-5069*

1806 THE EFFECTS OF RESISTANCE TRAINING ON A HIGH INTENSITY MANUAL MATERIALS HANDLING TASK IN WOMEN

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Manual materials handling tasks in the workplace place high demands on strength and endurance. It is recognized that men possess advantages (i.e. because of greater size and strength) over women during such tasks, but the potential of training interventions for the improvement of women's occupational performance is largely unexplored. We evaluated the effects of two resistance training programs: (1) upper body training (UBT) and (2) total body training (TBT) on a repetitive box lifting task (RBLT) and a 1 repetition maximum (1RM) boxlift (BL). The RBLT consisted of the maximum # of boxes lifted from the floor to a height of 1.32 m within a 10 min period (subjects moved between two boxes 2.4 m apart between lifts). 37 women (24±4 yrs, 166±6 cm, 64±9 kg) underwent either UBT (n=17) or TBT (n=20) and trained 3 x/wk for 6 months (3 sets/exercise, reps were periodized from 8 to 12; rest periods varied between 45-90 secs). A 20-30 min aerobic component concluded each workout. Testing occurred pre (T1), mid-way (T2) and post (T3) training. An ANOVA with repeated measures indicated significant ($p \leq 0.05$) training effects for both the RBLT and 1RM BL (T1<T2<T3), but no group or interaction effects. Results (mean±SD) were: 1RM BL (TBG: T1=30±5, T2=35±5, T3=38±4; T1 to T2 %Δ=~17%, T1 to T3%Δ=~27%; UBG: T1=31±6, T2=35±7, T3=38±6, T1 to T2 %Δ=~13%, T1 to T3 %Δ=~23%); RBLT (TBG: T1=89±24, T2=109±18, T3=118±16, T1 to T2 %Δ=~22%, T1 to T3 %Δ=~33%; UBG: T1=86±23, T2=108±26, T3=118±20, T1 to T2 %Δ=~26%, T1 to T3 %Δ=~37%). These data indicate that (1) adaptations in the upper body appear to account for a greater proportion than the lower body for the performance changes and (2) women can continue to exhibit performance improvements beyond 3 month of training. *DOD US Army Grant DAMD 17-95-5069 to WJK*

SIZE FRACTIONATION OF hGH IN PLASMA OF YOUNG WOMEN: EFFECTS OF ACUTE HEAVY RESISTANCE EXERCISE.

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Although there are data to indicate that circulating hGH increases in response to acute resistance exercise (Kraemer et al, *J. Appl. Phys.* 69:1442. 1990), details concerning molecular forms and biological activities of the hormone are lacking. We studied plasma hGH in 60 untrained women (22±2 yrs) before and immediately after acute heavy resistance exercise. Plasma samples were fractionated by Sephacryl S-100HR column chromatography into 3 size classes (fr. A, MW >60 K; fr. B, MW 30-60 K; and fr. C, MW <30 K). After lyophylization, samples were assayed for hGH concentrations by RIA (both Nichols and NIDDK kits) in addition to the tibial line assay in the hypox rat. RIA results were expressed in terms of NIH hGH standard AFP-4793B. Sample aliquots were also treated with glutathione (GSH, 10 mM, 24 hrs at RT) prior to assay. Significance was tested by MANOVA ($p<0.05$) for the main treatment effects (i.e. exercise, fractions, assay methods and GSH treatment). Major findings. Exercise increased hGH in all fractions except A. The Nichols assay yielded higher values than the NIDDK assay in the unfractionated and B samples, but the values were not different in A and C between the two kits [in ng/ml, Nichols pre-exercise unfractionated:3.3; A:0.9<B:3.0<C:3.9; post-exercise unfractionated:11.2; A:2.6<B:9.5=C:9.0] [NIDDK pre-exercise unfractionated:1.8; A:0.6<B:1.9<C:3.8; post-exercise unfractionated:4.0; A:1.6<B:5.9<C:9.2]. GSH treatment significantly increased hGH concentrations in the unfractionated, B and C samples; however it had no effect on A for any sample. Importantly, GSH resulted in a greater exercise induced increase in hGH, suggesting the presence of more disulfide linked aggregates in the samples post-exercise. Finally, there were no significant differences in hGH measured by the tibial line assay, either 1) among the fractions, or 2) between pre- and post-exercise samples. Approximately 70% of the tibial line activity was distributed equally between fractions A and B. Summary. Although all plasma samples were active in the tibial line assay, acute exercise had no effect. The RIA kit using the monoclonal hGH antibody yielded higher estimates of hGH concentrations than the kit using the polyclonal antibody. Acute heavy resistance exercise in young women resulted in significant changes in some of the three size classes of plasma hGH obtained after size exclusion chromatography. Some of these appeared to be attributed to disulfide linked aggregates, especially in the 30-60K fraction. (Supported by DOD US Army DAMD 17-95-5069)

PROLACTIN RESPONSES TO ACUTE RESISTANCE EXERCISE IN UNTRAINED WOMEN: RELATIONSHIP TO CORTISOL AND TESTOSTERONE

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Prolactin (PRL) is a stress hormone secreted by the anterior pituitary gland which may impact cortisol (CORT) and testosterone (TEST) release. Prior research has focused on the effects of aerobic exercise on PRL, however, few data exist regarding resistance exercise. This study determined the effect of an acute resistance exercise test (ARET) on PRL responses and its relationship to CORT and TEST responses. Venous blood was obtained from forty-seven eumenorrheic women (22 ± 3 yr.; 165 ± 6 cm; 62 ± 8 kg; 25 ± 5 %BF) pre and post an ARET (6 sets of 10RM squats separated by 2 min rest periods). Radioimmunoassays determined PRL, TEST, and CORT concentrations. Results demonstrated significant ($p \leq 0.05$) elevations (mean±SE) in PRL (15±1 vs. 25±2 µg/L), TEST (1.2±0.1 vs. 1.5±0.1 nmol/L), CORT (838±64 vs. 914±62 nmol/L), and lactate (LACT) (2.1±0.1 vs. 10.4±0.5 mmol/L). Pre PRL concentrations were significantly correlated with %Δ CORT (r=-0.30) and %Δ PRL (r=-0.30) but not %Δ T (r=0.07) or %Δ L (r=-0.02). In addition, %Δ PRL was correlated with %Δ C (r=0.75) and %Δ L (r=0.33) but not %Δ T (r=0.18). These results indicate that in untrained women, PRL is more responsive to resistance exercise than TEST or CORT. Also, resting basal PRL and %Δ PRL responses are more highly associated with CORT than TEST. The association between %Δ PRL and %Δ L support previous data suggesting a link between exercise intensity and PRL release. PRL responses to resistance exercise may be a useful marker for quantifying the overall intensity of the exercise performed.

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COMPARISON OF ABSOLUTE STRENGTH VS ABSOLUTE OCCUPATIONAL LIFTING PERFORMANCE IN UNTRAINED MEN AND WOMEN

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It is well established that, on average, men have a higher absolute strength than women. However, how the magnitude difference in muscular strength compares to the magnitude difference in occupational lifting performance (OLP) and whether men (M) and women (W) exhibit the same relationship between static measures of physical performance and dynamic OLP is unknown. This study compared the magnitude of absolute differences in strength (i.e. bench press [BP], squat [SQ], 1 RM boxlift from floor to 132 cm.[BL]), and aerobic capacity (2 mile run time [2MRT]), to OLP in 56 men (23±3 yrs, 177± 6 cm, 82±16 kg, 15±5 %BF) and 120 women (23±4 yrs, 166±7 cm, 64±10 kg, 25±5 %BF). OLP was calculated as total work (J) performed in 10 minutes by repetitively lifting a 20.5 kg metal box (47 cm x 23 cm x 31 cm) from the floor to a height of 132 cm (subjects were required to move between two boxes 2.4 m apart between lifts). M had significantly ($p \leq 0.05$) higher values than W (% difference between M & W is given in[]) for BP (87±21 vs. 32±7 kg; [63%]), SQ (108±26 vs. 52±12 kg; [52%]), BL (62±12 vs 30±5 kg [39%]), 2MRT (964±164 vs. 1214±231 secs; [26%]) and OLP (37163±5626 vs. 22704±6187 J; [39%]). Moderate correlations ($p \leq 0.05$) were observed for M and W between BP (M: r=0.49; W: r=0.56), SQ (M: r=0.45; W: r=0.48), BL (M: r=0.41; W: r=0.54), 2MRT (M: r=-0.54; W: -0.54) and OLP. We conclude that the relative gender difference in OLP requiring both strength and endurance is *less* than what is observed between men and women for 1RM strength measures.

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1689 PLASMA CORTISOL ELEVATION ON LYMPHOCYTE PROLIFERATION RESPONSE TO MITOGENS AFTER ACUTE RESISTANCE EXERCISE IN WOMEN

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In order to examine the effects of high (>1000 nmol·L^{-1}) and low (<500 nmol·L^{-1}) concentrations of cortisol on lymphocyte proliferation after acute heavy resistance exercise, 8 high (23.5 ± 3.2 yrs) and 8 low (22.1 ± 3.4 yrs) responders were studied from a population of 46 healthy but non-strength trained women. The resistance exercise test consisted of performing six sets of 10 repetition maximum (RM) squats with 2 minutes rest between sets utilizing a computerized Plyometic Power System. Blood samples were obtained at pre-exercise and immediately post exercise. Lymphocyte responses to pokeweed mitogen (PWM) were determined through the incorporation of triated thymidine. Plasma cortisol was measured via standard solid phase RIA techniques. The squat exercise significantly decreased lymphocyte proliferation response to PWM in high cortisol concentration group (29616 to 20190 CPM: $p \leq 0.05$) but not in low cortisol concentration group (33326 to 31990 CPM:$p > 0.05$). The data indicate plasma cortisol elevation during the exercise may be associated with the decreased lymphocyte T and B cell proliferation response. Thus the exercise-induced cortisol elevation may partially explain the mechanism of immuno suppression that might result in susceptible to pathogens immediately after the heavy resistance exercise training session.

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1688 EXERCISE-INDUCED TRAFFICKING VIA L-SELECTIN AND VLA-4 INTEGRIN DIFFERS BETWEEN LYMPHOCYTES AND NEUTROPHILS

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L-selectin and VLA-4 integrin are adhesion molecules that influence trafficking and homing of leukocytes. The mechanism underlying exercise-induced fluctuations in lymphocytes and neutrophils involves surface adhesion molecules, however, the roles of L-selectin and VLA-4 integrin have not been determined. It is known that VLA-4 integrin is not typically expressed on neutrophils. The aim of this study was 1) to determine whether expression of L-selectin and VLA-4 integrin are altered by exercise; and 2) to compare trafficking of lymphocytes and neutrophils with respect to these molecules. Blood samples from 29 females were collected immediately before and after performance of 6 sets of 10 repetition maximum squats, a high-intensity, anaerobic exercise lasting about 20 minutes. Expression of L-selectin and VLA-4 integrin were determined with flow cytometry using FITC conjugated CD62L and PE conjugated CD49d monoclonal antibodies, respectively. Lymphocytes increased ($p<0.001$) by 1.71 x 10^9 cells·l^{-1}, of which 1.14 x 10^9 cells·l^{-1} were CD49d+ and 0.37 x 10^9 cells·l^{-1} were CD62L+. Neutrophils increased ($p<0.001$) by 1.43 x 10^9 cells·l^{-1}, all of which were CD62L+. The fluorescence intensity of CD62L+ neutrophils increased ($p<0.05$), indicating increased expression of L-selectin during exercise. Thus, it is concluded that while the VLA-4 integrin may be involved in lymphocyte recruitment to the circulation during exercise, L-selectin plays a less crucial role. Conversely, while increased L-selectin expression can account for all of the neutrophils recruited to the circulation, VLA-4 integrin, as expected, played no role in this process.

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1600 TESTOSTERONE AND SHBG RESPONSES TO ACUTE RESISTANCE EXERCISE IN YOUNG HEALTHY WOMEN: EFFECTS OF REGIONAL FAT DISTRIBUTION.

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Regional fat distribution (RFD) has been associated with metabolic derangements in populations with obesity (e.g. upper body fat patterning is associated with higher levels of free testosterone (FT) and lower levels of sex-hormone binding globulin (SHBG)). The extent to which this relationship is true in healthy female populations and whether RFD influences androgen responses to resistance exercise has not been fully described. This study examined the effects of RFD on total testosterone (TT), FT, and SHBG responses to an acute resistance exercise test (ARET) among 47 women (22 ± 3 yr.; 165 ± 6 cm; 62 ± 8 kg; 25 ± 5 %BF; 23 ± 3 BMI). RFD was characterized by 2 separate indices: waist-to-hip ratio (WHR) and ratio of upper arm fat to mid-thigh fat (ALFATR) assessed via magnetic resonance imaging. The ARET consisted of 6 sets of 10RM squats separated by 2 min rest periods. Blood was obtained via venipuncture pre and post the ARET. TT, FT, and SHBG concentrations were determined by radioimmunoassay. Subjects were divided into tertiles from the indices of RFD and statistical analyses were performed via an ANOVA with repeated measures (RFD and exercise as main effects). Significant ($p \leq .05$) group effects existed for ALFATR, but not WHR. This indicated that women with upper body fat patterning possessed higher concentrations of FT (7.33 vs. 10.81 pmol/L for ALFATR tertiles 1 and 3 respectively). Main effects were observed for exercise demonstrating that the ARET served as a potent stimulus for acute increases in TT (1.24 vs. 1.55 nmol/L;~25% rise), FT (~24% rise) and SHBG (~4%).We conclude that for young healthy women: 1) resistance exercise can induce transient increases in androgen levels and 2) the use of ALFATR may be more discriminant than the WHR for assessing metabolic profiles associated with RFD. *DOD US Army Grant DAMD 17-95-C-5069*

GROWTH HORMONE AND INSULIN-LIKE GROWTH FACTOR 1 RESPONSES TO ACUTE RESISTANCE EXERCISE IN UNTRAINED WOMEN

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While serum growth hormone (GH) increases with exercise have been consistently observed, serum insulin-like growth factor 1 (IGF-1) responses have been equivocal. In addition, little is known about IGF-1 responses in women after acute resistance exercise. The purpose of this study was to examine serum GH, IGF-1 and lactate responses to an acute resistance exercise protocol (RE) among 47 women (22±3 yr.; 165±6 cm; 62±8 kg; 25±5 %BF). Venous blood was obtained from subjects via pre- and post-RE (6 sets of 10RM squats separated by 2 min). Serum GH and IGF-1 concentrations were then determined by radioimmunoassay. The RE resulted in significant ($p \leq .05$) increases in lactate (2.1±.8 vs. 10.4±3.2 mmol/L) and GH (4.9±6.3 vs. 16.6±8.8 µg/L), but not in IGF-1 (36.4±9 vs. 38.0±8.4 nmol/L). Individual IGF-1 responses, however, were highly variable with changes ranging from -40% to +49%. Tertiles based on these %Δs in IGF-1 revealed a 13±9% decrease (40.8±10 vs. 35.0±6 nmol/L) in tertile 1 and a 27±10% increase (31.0±8 vs. 39.6±10 nmol/L) in tertile 3; pre-IGF-1 values between these tertiles also differed. IGF-1 %Δs were not correlated with pre-exercise GH or %ΔGH values but were negatively correlated with pre-exercise IGF-1 values ($r = -.51$). These data confirm the independence of IGF-1 exercise responses from immunoreactive GH, and also suggest that pre-exercise values of IGF-1 may be a factor associated with the potential IGF-1 response to exercise in women. *DOD US Army Grant DAMD 17-95-C-5069*

995 LYMPHOCYTE PROLIFERATION RESPONSE TO MITOGENS IN WOMEN AFTER ACUTE HEAVY RESISTANCE EXERCISE

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Lymphocyte proliferation can be used to assess the responsiveness to activating stimuli. The effects of exercise on lymphocyte proliferation have been investigated largely with aerobic exercise. However, few studies are available regarding lymphocyte function and resistance exercise in women. The present study examined the effects of acute heavy resistance exercise on the lymphocyte proliferation response to two different mitogens, concanavalin A (ConA), which stimulates T cell proliferation, or pokeweed mitogen (PWM), which stimulates B cell and T cell proliferation. Forty-six healthy but non-strength trained women (X ± SD; 22.5 ± 3.5 yr; 61.1 ± 8.2 kg; 162.2 ± 16.0 cm) participated in the resistance exercise test which consisted of performing six sets of 10 repetition maximum squats with two minutes rest between sets utilizing a computerized Plyometric Power System. Blood samples were obtained at pre-exercise and immediately post-exercise, and incorporation of tritiated thymidine by lymphocytes in response to ConA (10.0 µg·ml^{-1}) or PWM (2.5 µg·ml^{-1}) was determined. Following the squat exercise, there was a significant ($p \leq 0.05$) decrease in lymphocyte responsiveness to PWM (X ± SD; 26.5 ± 11.9 vs 22.2 ± 11.8 CPM x 1000), but no significant difference in response to ConA (49.7 ± 23.0 vs 46.8 ± 24.6 CPM x 1000). Thus, these data indicated that the acute heavy resistance exercise in women transiently inhibited PWM specific activation pathways for B and T lymphocyte proliferation

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SERUM INSULIN-LIKE GROWTH FACTOR-1 CONCENTRATIONS REMAIN UNCHANGED IN THE PRESCENCE OF MUSCULAR HYPERTRO?HY FOLLOWING RESISTANCE TRAINING

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Insulin-like growth factor-1 (IGF-1) exhibits robust mitogenic actions. It is unlcear whether IGF-1's role impacting muscle hypertrophy is mediated via systemic and/or local mechanisms. This study examined serum IGF-1 responses in 37 women (22±3 yr, 165±6 cm, 64±8 kg, 26±6%BF) before and after both acute and chronic resistance exercise. Acute exercise consisted of a heavy resistance exercise test (HRET) (6 sets of 10RM squats separated by 2 min rest); chronic exercise consisted of 6 months of total body periodized resistance training (PRT). For PRT, subjects were divided into a total body strength/hypertrophy group or a total body strength/power group. Programs were differentiated by number of repetitions performed and rest between sets. Blood was obtained pre and post HRET both before and after PRT. IGF-1 was determined by an IRMA. Magnetic resonance imaging assessed changes in arm (A) and thigh (T) muscle cross-sectional area (MCSA). A repeated measures ANOVA tested for group, exercise, and training effects ($p<.05$). AMCSA (pre:32±5 vs. 38±5 cm2; 16%) and TMCSA (pre:125±16 vs. post: 134±15 cm2, 8%) increased after PRT. For IGF-1, there were no main effects for group or training (pre-PRT: 247 vs post-PRT: 251 ng/ml), however, main effects were observed for HRET (pre-HRET: 235 vs post-HRET: 262 ng/ml). Results demonstrate that serum IGF-1 concentrations increase after acute resistance exercise but are not altered following chronic PRT. These data suggest that IGF-1's role im mediating training-induced muscle hypertrophy may be more local than systemic.

116 SERUM CORTISOL ELEVATIONS AND LEUKOCYTE SUBSET CONCENTRATIONS AFTER ACUTE HEAVY RESISTANCE EXERCISE IN WOMEN

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Cortisol has been shown to cause neutrophilia, lymphocytopenia, and monocytopenia. However, few studies are available regarding the role of serum cortisol elevation in the immune system of women after resistance exercise. To examine the high (> 1000 nmol L^{-1}) and low (< 500 nmol L^{-1}) concentrations of serum cortisol for the leukocyte subset concentrations after acute heavy resistance exercise, eight high (23.5 ± 3.2 yrs) and eight low (22.1 ± 3.4 yrs) responders were studied from a population of 46 healthy, but non-strength trained women. The resistance test consisted of six sets of 10 RM squats with two minutes rest between sets utilizing a computerized Plyometric Power System. Blood samples were obtained at pre-exercise and immediately post-exercise. Serum cortisol was measured using an ^{125}I solid-phase radioimmunoassay. Leukocyte subset proportions were measured by immunofluorescent staining with subset specific monoclonal antibodies and analyzed using flow cytometry. Results from a two-way ANOVA analysis indicated that the squat exercise significantly ($p \leq 0.05$) increased lymphocyte, monocyte, and granulocyte concentrations of both groups. However, only granulocyte concentration of high cortisol group (pre: 4.88; post: 6.95: x 10^6 ml^{-1})was significantly greater than one of low cortisol group (pre: 3.69; post: 5.23: x 10^6 ml^{-1}). Thus, the high cortisol levels may have played a role in the increased granulocyte concentration which could be related to muscle tissue damage and inflammation after acute heavy resistance exercise.

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Acute Resistance Exercise in Women Reduces Lymphocyte Proliferation in Response to Mitogens

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To determine the influence of muscular strength on lymphocyte proliferation after heavy resistance exercise as a measure of immunologic function, this study recruited active, healthy, but non-strength-trained women. The top and bottom 8 women (22.5 ± 3.1 yrs) were obtained from a total strength testing distribution of 50. The 2 groups were based on a significant ($p < 0.05$) difference in 1-RM squat strength (low: 39.9 ± 4.6 kg, 0.65 ± 0.08 kg · kg^{-1} · BM^{-1}; high: 72.2 ± 10.7 kg, 1.1 ± 0.12 kg · kg^{-1} · BM^{-1}) and no significant difference in body mass. Each participated in an exercise testing session of 6 sets of 10-RM squat with 2 min rest between sets. Blood samples were obtained preexercise and 5 min postexercise. Lymphocyte responses to pokeweed mitogen (PWM) were determined through the incorporation of tritiated thymidine. The squat exercise significantly decreased lymphocyte responses to PWM in the high strength group but not in the low strength group. These data indicate that the squat transiently reduced B and T lymphocyte proliferative responses to PWM in stronger individuals. This effect may be due to the high absolute total work and greater exercise stress from the resistance exercise protocol in the high strength group. Intense resistance exercise workouts may cause a transient depression in immune function, especially in women who have a greater functional capacity (i.e., higher 1-RM), thereby rendering them potentially more susceptible to pathogens immediately after a workout.

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274 GROWTH HORMONE, TESTOSTERONE, STRENGTH AND HYPERTROPHY CHANGES IN WOMEN AFTER 6 MONTHS OF PERIODIZED RESISTANCE TRAINING

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A synergism between growth hormone and testosterone is known to exist in men. However, the effects of chronic training on adaptations of these hormones to acute resistance exercise and their relationship to muscular hypertrophy remain to be fully elucidated, particularly in women. This study examined the effects of 6 months of resistance training on acute exercise-induced responses of immunoreactive growth hormone (IGH), total testosterone (TT), and free testosterone (FT), 1RM squat strength (strength) and thigh muscle cross-sectional area (TMCSA) in 38 women. A total body training group (TBTG; n =22) and an upper body training group (UBTG; n=18) and trained 3 days/wk for 6 months in a periodized fashion (repetitions varied between 8 and 12, rest intervals between sets varied between 45 and 90 secs). A 20-30 minute aerobic conditioning session followed each workout. Venous blood samples were obtained pre and post an acute resistance exercise test ([ARET] 6 sets of 10RM squats separated by 2 min rest periods) and MCSA was assessed via magnetic resonance imaging on three separate occasions during training (month 0 [T1] month 3 [T2] and month 6 [T3]. An ANOVA with repeated measures ($p \leq 0.05$) revealed significant training and interaction effects. Mean±SD: TBTG (strength (kg): T1=54±12 ,T2=63±11, T3=69±14); (MCSA (cm^2): T1=126±17, T2=129±15 , T3=133±14); UBTG (strength (kg): T1=52±10 ,T2=58±10, T3=59±9); (MCSA (cm^2): T1=123±18, T2=122±17 , T3=126±17). The T1 %ΔFT for ARET was significantly associated with T1 to T3 MCSA Δs ($r=0.35$). The ARET induced elevations in IGH, TT, and FT and training X pre-post ARET interactions suggest that concomitant with increases in strength and hypertrophy after chronic heavy resistance training are alterations in the hormonal milieu after acute resistance exercise. *DoD US Army Grant 17 95-C-5069 to WJK*

277 GROWTH HORMONE VARIANTS AND BIOACTIVITY IN RESPONSE TO HEAVY RESISTANCE EXERCISE IN WOMEN

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An awareness of hGH's polymorphism (over 15 variants identified) now exists but limited data are available as to the responses of various molecular variants to exercise. This study examined the effects of an acute heavy resistance exercise protocol ([HREP]; 6 sets of 10RM squats separated by 2 min rest periods) on the concentration, molecular size, immunoreactivity, and bioactivity of hGH in 22 untrained women (22±2yrs). Blood samples were obtained by venipuncture pre- and immediately post-HREP. Plasma fractionation by Sephacryl S-100HR column chromatography prior to measurement of hGH was employed to partition proteins and hGH variants into 3 size classes; fraction A (apparent MW >60 kd), fraction B(30-60 kd), and fraction C (<30 kd). Neat and fractionated samples were assayed for bioactive hGH concentration[i.e., two assays: the Nb2 lymphocyte proliferation assay and the tibial line bioassay in the hypox rat] and immunoreactive hGH concentrations via monoclonal RIA. Significant ($p \leq 0.05$) increases after HREP in hGH were observed for the RIA for the neat, and in the A and B fractions. Thus, post-exercise samples for RIA appeared to increase aggregation with either other hGH molecules or hGH binding proteins. The Nb2 bioassay demonstrated no changes in bioactivity of hGH after HREP. The tibial line bioassay results showed no exercise-induced changes in the total sample pool. However, closer study of the data revealed two sub-groups of responders post-exercise. Significant increases or decreases occurred when cortisol values were lower (C increase); higher (C decrease); IGF-1 values higher (B and C increases); lower (B and C decreases). Fraction A showed none of these responses. These results demonstrate that hGH molecular variants respond differentially based upon the assay used and the array of hormonal responses in the exercising subject. *DOD US Army DAMD 17-95-5069*

924 THE DEVELOPMENT OF UPPER BODY PERFORMANCE IN WOMEN AFTER DIFFERENTIAL RESISTANCE TRAINING PROGRAMS

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The development for upper body performance in women is not well studied. It is thought that the use of loads ranging between 80-95% 1RM with longer (i.e. >2 min) rest periods performed in an "explosive type" manner are required to optimally train the neuromuscular system for the attainment of maximal force and power production. To test this hypothesis, 35 untrained women (23±4 yrs; 165±7 cm ; 63±8 kg) were randomly placed into either a total body strength power (TBSP, n=15) or a total body strength hypertrophy (TBSH, n=20) group. Both groups underwent periodized training 3x/wk for 12 wks: The TBSP group performed sets with loads at 80-95%1RM; reps ranging from 3-8 with 2 min rest period between sets; the TBSH group performed sets with loads at 60-75%1RM; reps ranging from 8-12 and 45-90 sec rest between sets. Bench press 1RM and peak power, rate of force development, and peak force was assessed via loaded bench throws (30% BP 1RM) with the aid of the Plyometric Power System pre and post training. Significant ($p \leq 0.05$) training effects were seen for all variables .

Variables	Group	Pre Values (±SD)	Post (± SD)	% Δ
PEAK POWER (w)	TBSP	163.9±74	203.4± 79.4	24
	TBSH	154.3±45.7	192.7 ± 57.6	23
RFD (N/s)	TASP	280.1± 133	443.5±205.7	58
	TBSH	333.9± 2.9	381.4±175.5	14
FORCE (N)	TBSP	143.7± 48.9	185.8± 54.5	29
	TBSH	147.5± 54.4	174± 53.2	18
1RM BP (Kg)	TBSP	33.1± 8.4	40.8±10.1	23
	TBSH	32.2± 8.3	37.20± 8.4	15

These data demonstrate that women can experience gains in upper body strength, power, force and rate of force development within 12 weeks. However, 12 weeks is not long enough to observe differences in performance outcomes in delineated programs. *DOD US Army DAMD 17-95-5069*

937 POWER AND STRENGTH IN WOMEN: ADAPTATIONS FOLLOWING SIX MONTHS OF RESISTANCE TRAINING

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This study determined the effects of a periodized, total body strength/power (TBSP: 3-8 repetitions for 3 sets each of 8 exercises performed explosively, 120 sec rest between sets) and a total body strength/hypertrophy (TBSH: 8-12 repetitions for 3 sets each of 8 exercises, 45-90 sec rest between sets) training on power and strength in women. Thirty-six untrained women (23±4 yr., 165±7 cm, 63±8 kg) were randomly placed into TBSP (n=17) or TBSH (n=19) groups and trained 3 days/wk for 6 months. The women were tested before training (T1), after 3 months (T2), and after 6 months (T3) in 1-RM barbell squats, high pulls, and 30% of 1-RM jump squat power (all on a Plyometric Power System).

Variable	Group	T1 (± SD)	T2 (± SD)	Δ%	T3 (± SD)	Δ%	Δ% Total
1-RM Sq (kg)	TBSP	53 ± 12	65± 11	22.6	73 ±10	12.3	37.7
	TBSH	52 ± 11	63 ± 12	21.2	70 ± 14	11.1	34.6
1-RM HP (kg)	TBSP	34 ± 7	39 ± 7	14.7	41 ± 6	5.1	20.6
	TBSH	32 ± 5	34 ± 6	6.3	35 ± 6	2.9	9.4
Peak Pwr (W)	TBSP	1650 ± 372	1833 ± 370	11.1	1952 ± 406	6.5	18.3
	TBSH	1699 ± 250	1807 ± 278	5.98	1838 ± 259	1.7	8.2

An ANOVA with repeated measures indicated significant ($p \leq 0.05$) training effects for both groups in all variables. The TBSP group showed greater gains in the high pull and power output than did the TBSH group, yet both groups improved equally in the squat. Finally, this study demonstrated that, over six months, women can dramatically improve their power and strength with a periodized resistance training program, dependent on the specificity of the program.

D.O.D. U.S. ARMY GRANT 17 95-C-5069 to WJK

994 DECREASED LYMPHOCYTE PROLIFERATION IN RESPONSE TO MITOGENIC AND ANTIGENIC STIMULATION DURING RESISTANCE TRAINING

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While the exercise stress during power resistance training can be tremendous, this type of training is seldom considered when evaluating the effects of exercise on the immune system. The purpose of this investigation was to determine whether the proliferative response of lymphocytes was affected by progressive, power, resistance training. Female subjects (n=9) performed 3 power-based resistance training sessions per week. Resting blood samples were collected from training subjects and seasonally matched controls (n=3) at 0, 3, and 6 months. Peripheral blood mononuclear cells were isolated and cultured with several mitogens (phytohemagglutinin (PHA), Concanavalin A (Con A), and pokeweed mitogen PWM), a superantigen (*staphylococcus a.* cowans (Sac)), and a recall antigen (tetanus toxoid). Proliferation of stimulated lymphocytes was quantitated via the incorporation of tritiated thymidine. While lymphocyte proliferation in seasonally matched control subjects tended to increase over the three sampling periods, proliferation in the training group decreased. This difference was significant for a high concentration of Con A (group, $P<0.01$), low and high concentrations of PWM (group $P<0.01$ and group x time $P<0.05$, respectively), and low and high concentrations of Sac (group $P<0.01$ and $P<0.05$, respectively). For example, the response to Con A went from (mean ± SD x 10^3) 58.6 ± 17.1 to 49.6 ± 10.1 to 48.2 ± 11.6 cpm in the training group, and from 67.9 ± 16.9 to 69.6 ± 26.8 to 88.2 ± 30.8 cpm in the control group at 0, 3, and 6 months, respectively. These data suggest that the power resistance training was associated with a decrease in the proliferation responses of peripheral blood lymphocytes.

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355 PREDICTION OF REPETITIVE LIFTING ABILITY IN UNTRAINED WOMEN FROM MUSCULAR STRENGTH AND ENDURANCE

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The relationship between characteristics of muscular performance (e.g. size, strength, power, endurance) and occupational tasks has not been clearly defined. This study assessed the physical performance of 47 untrained women (22 $\pm$ 3 yr; 165 $\pm$ 6 cm; 62 $\pm$ 8 kg; 25 $\pm$ 5 %BF) and identified via multiple regression analysis the best predictors of a repetitive lifting test (RLT). The RLT consisted of the maximum number of boxes (20.45 kg) that could be lifted from the floor to a height of 132 cm within a 10 min period (subjects were required to move between two boxes 2.4 m apart between lifts). Independent variables (IVs) included weight (wt), height (ht), MRI assessed arm and leg cross-sectional area, muscular strength 1RMs (bench press, squat, high pull, boxlift), upper and lower body explosive power (mechanical power determined from bench press throws and jump squats), muscular endurance (# of push-ups in 2 min and # of squat repetitions at a controlled rate with a 45 kg load) and aerobic capacity assessed from a 2 mile run (2MR in secs). The mean $\pm$SD (range) for the RLT was : 92$\pm$25(20-159). For all IVs (excluding the 2MR) the following equation was generated : RLT (#) = 2.4(1RM boxlift in kg) + 0.70 (# of push-ups in 2 min) + 0.94 (Ht) - 146 [R= 0.83; SEE = 15; $p \leq 0.05$]. When 2MR was included, the equation was: RLT (#) = 2.9(1RM boxlift in kg) - 0.05 (2MR in secs) + 73 [R = 0.83; SEE = 14; $p \leq 0.05$]. Because the 1RM boxlift correlated higher than any of the other variables ($r = 0.74$) with RLT and entered into both equations, these results illustrate the importance of task-specific strength for predicting successful job performance. Also, the predictive value of a measure of aerobic capacity for RLT suggests that women can also benefit from endurance training for repetitive occupational tasks requiring total body strength and local muscular and aerobic endurance.

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PROLACTIN RESPONSES TO ACUTE RESISTANCE EXERCISE IN UNTRAINED WOMEN: RELATIONSHIP TO CORTISOL AND TESTOSTERONE

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Prolactin (PRL) is a stress hormone secreted by the anterior pituitary gland which may impact cortisol (CORT) and testosterone (TEST) release. Prior research has focused on the effects of aerobic exercise on PRL, however, few data exist regarding resistance exercise. This study determined the effect of an acute resistance exercise test (ARET) on PRL responses and its relationship to CORT and TEST responses. Venous blood was obtained from forty-seven eumenorrheic women (22 ± 3 yr.; 165 ± 6 cm; 62 ± 8 kg; 25 ± 5 %BF) pre and post an ARET (6 sets of 10RM squats separated by 2 min rest periods). Radioimmunoassays determined PRL, TEST, and CORT concentrations. Results demonstrated significant ($p \leq 0.05$) elevations (mean±SE) in PRL (15±1 vs. 25±2 µg/L), TEST (1.2±0.1 vs. 1.5±0.1 nmol/L), CORT (838±64 vs. 914±62 nmol/L), and lactate (LACT) (2.1±0.1 vs. 10.4±0.5 mmol/L). Pre PRL concentrations were significantly correlated with %Δ CORT ($r=-0.30$) and %Δ PRL ($r=-0.30$) but not %Δ T ($r=0.07$) or %Δ L ($r=-0.02$). In addition, %Δ PRL was correlated with %Δ C ($r=0.75$) and %Δ L ($r=0.33$) but not %Δ T ($r=0.18$). These results indicate that in untrained women, PRL is more responsive to resistance exercise than TEST or CORT. Also, resting basal PRL and %Δ PRL responses are more highly associated with CORT than TEST. The association between %Δ PRL and %Δ L support previous data suggesting a link between exercise intensity and PRL release. PRL responses to resistance exercise may be a useful marker for quantifying the overall intensity of the exercise performed.

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SIZE FRACTIONATION OF hGH IN PLASMA OF YOUNG WOMEN: EFFECTS OF ACUTE HEAVY RESISTANCE EXERCISE.

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Although there are data to indicate that circulating hGH increases in response to acute resistance exercise (Kraemer et al, *J. Appl. Phys.* 69:1442. 1990), details concerning molecular forms and biological activities of the hormone are lacking. We studied plasma hGH in 60 untrained women (22±2 yrs) before and immediately after acute heavy resistance exercise. Plasma samples were fractionated by Sephacryl S-100HR column chromatography into 3 size classes (fr. A, MW >60 K; fr. B, MW 30-60 K; and fr. C, MW <30 K). After lyophylization, samples were assayed for hGH concentrations by RIA (both Nichols and NIDDK kits) in addition to the tibial line assay in the hypox rat. RIA results were expressed in terms of NIH hGH standard AFP-4793B. Sample aliquots were also treated with glutathione (GSH, 10 mM, 24 hrs at RT) prior to assay. Significance was tested by MANOVA ($p<0.05$) for the main treatment effects (i.e. exercise, fractions, assay methods and GSH treatment). Major findings. Exercise increased hGH in all fractions except A. The Nichols assay yielded higher values than the NIDDK assay in the unfractionated and B samples, but the values were not different in A and C between the two kits [in ng/ml, Nichols pre-exercise unfractionated:3.3; A:0.9<B:3.0<C:3.9; post-exercise unfractionated:11.2; A:2.6<B:9.5=C:9.0] [NIDDK pre-exercise unfractionated:1.8; A:0.6<B:1.9<C:3.8; post-exercise unfractionated:4.0; A:1.6<B:5.9<C:9.2]. GSH treatment significantly increased hGH concentrations in the unfractionated, B and C samples; however it had no effect on A for any sample. Importantly, GSH resulted in a greater exercise induced increase in hGH, suggesting the presence of more disulfide linked aggregates in the samples post-exercise. Finally, there were no significant differences in hGH measured by the tibial line assay, either 1) among the fractions, or 2) between pre- and post-exercise samples. Approximately 70% of the tibial line activity was distributed equally between fractions A and B. Summary. Although all plasma samples were active in the tibial line assay, acute exercise had no effect. The RIA kit using the monoclonal hGH antibody yielded higher estimates of hGH concentrations than the kit using the polyclonal antibody. Acute heavy resistance exercise in young women resulted in significant changes in some of the three size classes of plasma hGH obtained after size exclusion chromatography. Some of these appeared to be attributed to disulfide linked aggregates, especially in the 30-60K fraction. (Supported by DOD US Army DAMD 17-95-5069)

1806 THE EFFECTS OF RESISTANCE TRAINING ON A HIGH INTENSITY MANUAL MATERIALS HANDLING TASK IN WOMEN

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Manual materials handling tasks in the workplace place high demands on strength and endurance. It is recognized that men possess advantages (i.e. because of greater size and strength) over women during such tasks, but the potential of training interventions for the improvement of women's occupational performance is largely unexplored. We evaluated the effects of two resistance training programs: (1) upper body training (UBT) and (2) total body training (TBT) on a repetitive box lifting task (RBLT) and a 1 repetition maximum (1RM) boxlift (BL). The RBLT consisted of the maximum # of boxes lifted from the floor to a height of 1.32 m within a 10 min period (subjects moved between two boxes 2.4 m apart between lifts). 37 women (24±4 yrs, 166±6 cm, 64±9 kg) underwent either UBT (n=17) or TBT (n=20) and trained 3 x/wk for 6 months (3 sets/exercise, reps were periodized from 8 to 12; rest periods varied between 45-90 secs). A 20-30 min aerobic component concluded each workout. Testing occurred pre (T1), mid-way (T2) and post (T3) training. An ANOVA with repeated measures indicated significant ($p \leq 0.05$) training effects for both the RBLT and 1RM BL (T1<T2<T3), but no group or interaction effects. Results (mean±SD) were: 1RM BL (TBG: T1=30±5, T2=35±5, T3=38±4; T1 to T2 %Δ=~17%, T1 to T3%Δ=~27%; UBG: T1=31±6, T2=35±7, T3=38±6, T1 to T2 %Δ=~13%, T1 to T3 %Δ=~23%); RBLT (TBG: T1=89±24, T2=109±18, T3=118±16, T1 to T2 %Δ=~22%, T1 to T3 %Δ=~33%; UBG: T1=86±23, T2=108±26, T3=118±20, T1 to T2 %Δ=~26%, T1 to T3 %Δ=~37%). These data indicate that (1) adaptations in the upper body appear to account for a greater proportion than the lower body for the performance changes and (2) women can continue to exhibit performance improvements beyond 3 month of training. *DOD US Army Grant DAMD 17-95-5069 to WJK*

923 CONTRIBUTION OF UPPER BODY TRAINING ON TOTAL BODY STRENGTH AND POWER IN YOUNG WOMEN

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The purpose of this investigation was to determine the contribution of upper body strength training to total body strength/power performance.. We examined the hypothesis that periodized upper body resistance training would aid in the increase in lower body power and strength in previously untrained young. 15 women (T) (baseline characteristics: 23 ± 2 yr, 164 ± 1 cm, 65 ± 0 kg, 24 ± 9 % BF) trained for 3 months in a periodized resistance total body program designed for gains in strength and power while 17 women (U)) (baseline characteristics: 22 ± 6 yr, 165 ± 2 cm, 64 ± 4 kg, 25 ± 4 % BF) participated in a similar program but with no lower body resistance training. All women were tested pre- and post-training for strength (1-RM squat [SQ], bilateral isometric leg extension [LX]), explosive power (peak watts generated during a jump squat at 30% of 1-RM SQ [JSQ]; and fat- and bone-free thigh muscle cross sectional area (assessed via magnetic resonance imaging [MSCA]). Results indicated that the T group made significant gains in all performance tests and MSCA, while the U group improved significantly only in the SQ, with no change of MCSA. The fact that the U group increased in the SQ but not the LX may be due in part to the strengthening of the shoulder girdle and torso which aided in the carriage and support of the bar during the 1-RM performance. Despite the fact that the prime movements tested by these lifts are of the lower body, the synergistic roles of the shoulder girdle and torso during the SQ play an important role throughout the eccentric and concentric phases of the lift. These data demonstrate that the upper body contribution to strength and power development is related to the added structural support for the load during maximal slow velocity 1-RM squat movements.
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1633 UPPER BODY RESISTANCE TRAINING IN WOMEN INCREASES ARM MUSCLE CROSS-SECTIONAL AREA BY A 20% AVERAGE

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This study determined the effects of 6 months of supervised, periodized upper body resistance training on women's upper body muscle cross-sectional area (MCSA). Subjects were placed into one of two groups: strength/power (S/P, n = 21) or strength/hypertrophy (S/H, n = 19). The groups were delineated by the repetitions and rest intervals between sets. Magnetic resonance imaging assessed the MCSAs of the singular muscles (i.e. biceps brachii, brachialis, and triceps brachii) of the upper arm at 3 points throughout training (pre (T1), mid (T2), and post (T3). An ANOVA with repeated measures revealed significant training effects for total and singular MCSAs (T1<T2<T3), with the exception of the brachialis. No group effects were revealed. * $p \leq 0.05$ different from previous timepoint

Training Group	Total MCSA	Biceps Brachii MCSA	Brachialis MCSA	Triceps MCSA
S/P				
T1	32.0±3.8	7.7±1.0	4.3±0.8	19.5±2.8
T2	35.7±4.7*	8.5±1.4*	4.7±.08*	21.5±3.1*
T3	38.4±4.4*	9.1±1.4*	4.7±.6	23.4±2.8*
T1 to T3 %Δ	*20.4±8.7*	*17.9±13.2*	*12.5±15.1*	*20.3±16.4*
S/H				
T1	32.3±5.3	7.8±1.7	4.9±.9	19.7±3.4
T2	36.6±5.8*	8.5±2.0*	5.2±.9*	22.2±3.6*
T3	38.5±7.5*	9.1±2.3*	5.3±1.1	23.2±4.5*
T1 to T3 %Δ	*19.0±10.3*	*16.4±11.7*	*8.1±13.0*	*18.0±10.5*

%Δs for singular MCSAs ranged from 8 to 20%. Total upper arm MSCA hypertrophied by 20%. This study firmly establishes that with optimally designed resistance training, women can exhibit *impressive* hypertrophy in upper body muscle throughout 6 months of training. *DOD US Army DAMD 17-95-5069*

1689 PLASMA CORTISOL ELEVATION ON LYMPHOCYTE PROLIFERATION RESPONSE TO MITOGENS AFTER ACUTE RESISTANCE EXERCISE IN WOMEN

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In order to examine the effects of high (>1000 nmol·L^{-1}) and low (<500 nmol·L^{-1}) concentrations of cortisol on lymphocyte proliferation after acute heavy resistance exercise, 8 high (23.5 $\pm$ 3.2 yrs) and 8 low (22.1 $\pm$ 3.4 yrs) responders were studied from a population of 46 healthy but non-strength trained women. The resistance exercise test consisted of performing six sets of 10 repetition maximum (RM) squats with 2 minutes rest between sets utilizing a computerized Plyometic Power System. Blood samples were obtained at pre-exercise and immediately post exercise. Lymphocyte responses to pokeweed mitogen (PWM) were determined through the incorporation of triated thymidine. Plasma cortisol was measured via standard solid phase RIA techniques. The squat exercise significantly decreased lymphocyte proliferation response to PWM in high cortisol concentration group (29616 to 20190 CPM: $p \leq 0.05$) but not in low cortisol concentration group (33326 to 31990 CPM:$p > 0.05$). The data indicate plasma cortisol elevation during the exercise may be associated with the decreased lymphocyte T and B cell proliferation response. Thus the exercise-induced cortisol elevation may partially explain the mechanism of immuno suppression that might result in susceptible to pathogens immediately after the heavy resistance exercise training session.

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COMPARISON OF ABSOLUTE STRENGTH VS ABSOLUTE OCCUPATIONAL LIFTING PERFORMANCE IN UNTRAINED MEN AND WOMEN

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It is well established that, on average, men have a higher absolute strength than women. However, how the magnitude difference in muscular strength compares to the magnitude difference in occupational lifting performance (OLP) and whether men (M) and women (W) exhibit the same relationship between static measures of physical performance and dynamic OLP is unknown. This study compared the magnitude of absolute differences in strength (i.e. bench press [BP], squat [SQ], 1 RM boxlift from floor to 132 cm.[BL]), and aerobic capacity (2 mile run time [2MRT]), to OLP in 56 men (23±3 yrs, 177± 6 cm, 82±16 kg, 15±5 %BF) and 120 women (23±4 yrs, 166±7 cm, 64±10 kg, 25±5 %BF). OLP was calculated as total work (J) performed in 10 minutes by repetitively lifting a 20.5 kg metal box (47 cm x 23 cm x 31 cm) from the floor to a height of 132 cm (subjects were required to move between two boxes 2.4 m apart between lifts). M had significantly ($p \leq 0.05$) higher values than W (% difference between M & W is given in[]) for BP (87±21 vs. 32±7 kg; [63%]), SQ (108±26 vs. 52±12 kg; [52%]), BL (62±12 vs 30±5 kg [39%]), 2MRT (964±164 vs. 1214±231 secs; [26%]) and OLP (37163±5626 vs. 22704±6187 J; [39%]). Moderate correlations ($p \leq 0.05$) were observed for M and W between BP (M: $r=0.49$; W: $r=0.56$), SQ (M: $r=0.45$; W: $r=0.48$), BL (M: $r=0.41$; W: $r=0.54$), 2MRT (M: $r=-0.54$; W: -0.54) and OLP. We conclude that the relative gender difference in OLP requiring both strength and endurance is *less* than what is observed between men and women for 1RM strength measures.

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1688 EXERCISE-INDUCED TRAFFICKING VIA L-SELECTIN AND VLA-4 INTEGRIN DIFFERS BETWEEN LYMPHOCYTES AND NEUTROPHILS

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L-selectin and VLA-4 integrin are adhesion molecules that influence trafficking and homing of leukocytes. The mechanism underlying exercise-induced fluctuations in lymphocytes and neutrophils involves surface adhesion molecules, however, the roles of L-selectin and VLA-4 integrin have not been determined. It is known that VLA-4 integrin is not typically expressed on neutrophils. The aim of this study was 1) to determine whether expression of L-selectin and VLA-4 integrin are altered by exercise; and 2) to compare trafficking of lymphocytes and neutrophils with respect to these molecules. Blood samples from 29 females were collected immediately before and after performance of 6 sets of 10 repetition maximum squats, a high-intensity, anaerobic exercise lasting about 20 minutes. Expression of L-selectin and VLA-4 integrin were determined with flow cytometry using FITC conjugated CD62L and PE conjugated CD49d monoclonal antibodies, respectively. Lymphocytes increased ($p<0.001$) by 1.71×10^9 cells·l^{-1}, of which 1.14×10^9 cells·l^{-1} were CD49d+ and 0.37×10^9 cells·l^{-1} were CD62L+. Neutrophils increased ($p<0.001$) by 1.43×10^9 cells·l^{-1}, all of which were CD62L+. The fluorescence intensity of CD62L+ neutrophils increased ($p<0.05$), indicating increased expression of L-selectin during exercise. Thus, it is concluded that while the VLA-4 integrin may be involved in lymphocyte recruitment to the circulation during exercise, L-selectin plays a less crucial role. Conversely, while increased L-selectin expression can account for all of the neutrophils recruited to the circulation, VLA-4 integrin, as expected, played no role in this process.

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995 LYMPHOCYTE PROLIFERATION RESPONSE TO MITOGENS IN WOMEN AFTER ACUTE HEAVY RESISTANCE EXERCISE

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Lymphocyte proliferation can be used to assess the responsiveness to activating stimuli. The effects of exercise on lymphocyte proliferation have been investigated largely with aerobic exercise. However, few studies are available regarding lymphocyte function and resistance exercise in women. The present study examined the effects of acute heavy resistance exercise on the lymphocyte proliferation response to two different mitogens, concanavalin A (ConA), which stimulates T cell proliferation, or pokeweed mitogen (PWM), which stimulates B cell and T cell proliferation. Forty-six healthy but non-strength trained women (X ± SD; 22.5 ± 3.5 yr; 61.1 ± 8.2 kg; 162.2 ± 16.0 cm) participated in the resistance exercise test which consisted of performing six sets of 10 repetition maximum squats with two minutes rest between sets utilizing a computerized Plyometric Power System. Blood samples were obtained at pre-exercise and immediately post-exercise, and incorporation of tritiated thymidine by lymphocytes in response to ConA (10.0 $\mu g \cdot ml^{-1}$) or PWM (2.5 $\mu g \cdot ml^{-1}$) was determined. Following the squat exercise, there was a significant ($p \leq 0.05$) decrease in lymphocyte responsiveness to PWM (X ± SD; 26.5 ± 11.9 vs 22.2 ± 11.8 CPM x 1000), but no significant difference in response to ConA (49.7 ± 23.0 vs 46.8 ± 24.6 CPM x 1000). Thus, these data indicated that the acute heavy resistance exercise in women transiently inhibited PWM specific activation pathways for B and T lymphocyte proliferation.

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1600 TESTOSTERONE AND SHBG RESPONSES TO ACUTE RESISTANCE EXERCISE IN YOUNG HEALTHY WOMEN: EFFECTS OF REGIONAL FAT DISTRIBUTION.

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Regional fat distribution (RFD) has been associated with metabolic derangements in populations with obesity (e.g. upper body fat patterning is associated with higher levels of free testosterone (FT) and lower levels of sex-hormone binding globulin (SHBG)). The extent to which this relationship is true in healthy female populations and whether RFD influences androgen responses to resistance exercise has not been fully described. This study examined the effects of RFD on total testosterone (TT), FT, and SHBG responses to an acute resistance exercise test (ARET) among 47 women (22 $\pm$ 3 yr.; 165 $\pm$ 6 cm; 62 $\pm$ 8 kg; 25 $\pm$ 5 %BF; 23 $\pm$ 3 BMI). RFD was characterized by 2 separate indices: waist-to-hip ratio (WHR) and ratio of upper arm fat to mid-thigh fat (ALFATR) assessed via magnetic resonance imaging. The ARET consisted of 6 sets of 10RM squats separated by 2 min rest periods. Blood was obtained via venipuncture pre and post the ARET. TT, FT, and SHBG concentrations were determined by radioimmunoassay. Subjects were divided into tertiles from the indices of RFD and statistical analyses were performed via an ANOVA with repeated measures (RFD and exercise as main effects). Significant ($p \leq .05$) group effects existed for ALFATR, but not WHR. This indicated that women with upper body fat patterning possessed higher concentrations of FT (7.33 vs. 10.81 pmol/L for ALFATR tertiles 1 and 3 respectively). Main effects were observed for exercise demonstrating that the ARET served as a potent stimulus for acute increases in TT (1.24 vs. 1.55 nmol/L;~25% rise), FT (~24% rise) and SHBG (~4%).We conclude that for young healthy women: 1) resistance exercise can induce transient increases in androgen levels and 2) the use of ALFATR may be more discriminant than the WHR for assessing metabolic profiles associated with RFD. *DOD US Army Grant DAMD 17-95-C-5069*

GROWTH HORMONE AND INSULIN-LIKE GROWTH FACTOR 1 RESPONSES TO ACUTE RESISTANCE EXERCISE IN UNTRAINED WOMEN B.C. Nindl, L.A. Gotshalk, J.S. Volek, F.S. Harman, S.A. Tokeshi,S.A. Mazzetti, C.C. Loebel, J.O. Marx, S.E. Gordon, N.D. Duncan, W.C. Hymer, M. Putukian, W.J. Sebastianelli and W.J. Kraemer (SPON: W.J. Kraemer).Ctr for Cell Resch, Ctr for Sports Med and Noll Physiol Resch Ctr, Penn State Univ, University Park, PA, 16802

While serum growth hormone (GH) increases with exercise have been consistently observed, serum insulin-like growth factor 1 (IGF-1) responses have been equivocal. In addition, little is known about IGF-1 responses in women after acute resistance exercise. The purpose of this study was to examine serum GH, IGF-1 and lactate responses to an acute resistance exercise protocol (RE) among 47 women (22±3 yr.; 165±6 cm; 62±8 kg; 25±5 %BF). Venous blood was obtained from subjects via pre- and post-RE (6 sets of 10RM squats separated by 2 min). Serum GH and IGF-1 concentrations were then determined by radioimmunoassay. The RE resulted in significant ($p \leq .05$) increases in lactate (2.1±.8 vs. 10.4±3.2 mmol/L) and GH (4.9±6.3 vs. 16.6±8.8 µg/L), but not in IGF-1 (36.4±9 vs. 38.0±8.4 nmol/L). Individual IGF-1 responses, however, were highly variable with changes ranging from -40% to +49%. Tertiles based on these %Δs in IGF-1 revealed a 13±9% decrease (40.8±10 vs. 35.0±6 nmol/L) in tertile 1 and a 27±10% increase (31.0±8 vs. 39.6±10 nmol/L) in tertile 3; pre-IGF-1 values between these tertiles also differed. IGF-1 %Δs were not correlated with pre-exercise GH or %ΔGH values but were negatively correlated with pre-exercise IGF-1 values ($r = -.51$). These data confirm the independence of IGF-1 exercise responses from immunoreactive GH, and also suggest that pre-exercise values of IGF-1 may be a factor associated with the potential IGF-1 response to exercise in women. *DOD US Army Grant DAMD 17-95-C-5069*

Acute Resistance Exercise in Women Reduces Lymphocyte Proliferation in Response to Mitogens

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To determine the influence of muscular strength on lymphocyte proliferation after heavy resistance exercise as a measure of immunologic function, this study recruited active, healthy, but non-strength-trained women. The top and bottom 8 women (22.5 ± 3.1 yrs) were obtained from a total strength testing distribution of 50. The 2 groups were based on a significant ($p < 0.05$) difference in 1-RM squat strength (low: 39.9 ± 4.6 kg, 0.65 ± 0.08 kg · kg^{-1} · BM^{-1}; high: 72.2 ± 10.7 kg, 1.1 ± 0.12 kg · kg^{-1} · BM^{-1}) and no significant difference in body mass. Each participated in an exercise testing session of 6 sets of 10-RM squat with 2 min rest between sets. Blood samples were obtained preexercise and 5 min postexercise. Lymphocyte responses to pokeweed mitogen (PWM) were determined through the incorporation of tritiated thymidine. The squat exercise significantly decreased lymphocyte responses to PWM in the high strength group but not in the low strength group. These data indicate that the squat transiently reduced B and T lymphocyte proliferative responses to PWM in stronger individuals. This effect may be due to the high absolute total work and greater exercise stress from the resistance exercise protocol in the high strength group. Intense resistance exercise workouts may cause a transient depression in immune function, especially in women who have a greater functional capacity (i.e., higher 1-RM), thereby rendering them potentially more susceptible to pathogens immediately after a workout.

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116 SERUM CORTISOL ELEVATIONS AND LEUKOCYTE SUBSET CONCENTRATIONS AFTER ACUTE HEAVY RESISTANCE EXERCISE IN WOMEN

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Cortisol has been shown to cause neutrophilia, lymphocytopenia, and monocytopenia. However, few studies are available regarding the role of serum cortisol elevation in the immune system of women after resistance exercise. To examine the high (> 1000 nmolL^{-1}) and low (< 500 nmolL^{-1}) concentrations of serum cortisol for the leukocyte subset concentrations after acute heavy resistance exercise, eight high (23.5 $\pm$ 3.2 yrs) and eight low (22.1 $\pm$ 3.4 yrs) responders were studied from a population of 46 healthy, but non-strength trained women. The resistance test consisted of six sets of 10 RM squats with two minutes rest between sets utilizing a computerized Plyometric Power System. Blood samples were obtained at pre-exercise and immediately post-exercise. Serum cortisol was measured using an ^{125}I solid-phase radioimmunoassay. Leukocyte subset proportions were measured by immunofluorescent staining with subset specific monoclonal antibodies and analyzed using flow cytometry. Results from a two-way ANOVA analysis indicated that the squat exercise significantly ($p \leq 0.05$) increased lymphocyte, monocyte, and granulocyte concentrations of both groups. However, only granulocyte concentration of high cortisol group (pre: 4.88; post: 6.95; x 10^6 ml^{-1})was significantly greater than one of low cortisol group (pre: 3.69; post: 5.23; x 10^6 ml^{-1}). Thus, the high cortisol levels may have played a role in the increased granulocyte concentration which could be related to muscle tissue damage and inflammation after acute heavy resistance exercise.

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SERUM INSULIN-LIKE GROWTH FACTOR-1 CONCENTRATIONS REMAIN UNCHANGED IN THE PRESCENCE OF MUSCULAR HYPERTROPHY FOLLOWING RESISTANCE TRAINING

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Insulin-like growth factor-1 (IGF-1) exhibits robust mitogenic actions. It is unlcear whether IGF-1's role impacting muscle hypertrophy is mediated via systemic and/or local mechanisms. This study examined serum IGF-1 responses in 37 women (22±3 yr, 165±6 cm, 64±8 kg, 26±6%BF) before and after both acute and chronic resistance exercise. Acute exercise consisted of a heavy resistance exercise test (HRET) (6 sets of 10RM squats separated by 2 min rest); chronic exercise consisted of 6 months of total body periodized resistance training (PRT). For PRT, subjects were divided into a total body strength/hypertrophy group or a total body strength/power group. Programs were differentiated by number of repetitions performed and rest between sets. Blood was obtained pre and post HRET both before and after PRT. IGF-1 was determined by an IRMA. Magnetic resonance imaging assessed changes in arm (A) and thigh (T) muscle cross-sectional area (MCSA). A repeated measures ANOVA tested for group, exercise, and training effects ($p<.05$). AMCSA (pre:32±5 vs. 38±5 cm2; 16%) and TMCSA (pre:125±16 vs. post: 134±15 cm2, 8%) increased after PRT. For IGF-1, there were no main effects for group or training (pre-PRT: 247 vs post-PRT: 251 ng/ml), however, main effects were observed for HRET (pre-HRET: 235 vs post-HRET: 262 ng/ml). Results demonstrate that serum IGF-1 concentrations increase after acute resistance exercise but are not altered following chronic PRT. These data suggest that IGF-1's role im mediating training-induced muscle hypertrophy may be more local than systemic.

274 GROWTH HORMONE, TESTOSTERONE, STRENGTH AND HYPERTROPHY CHANGES IN WOMEN AFTER 6 MONTHS OF PERIODIZED RESISTANCE TRAINING

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A synergism between growth hormone and testosterone is known to exist in men. However, the effects of chronic training on adaptations of these hormones to acute resistance exercise and their relationship to muscular hypertrophy remain to be fully elucidated, particularly in women. This study examined the effects of 6 months of resistance training on acute exercise-induced responses of immunoreactive growth hormone (IGH), total testosterone (TT), and free testosterone (FT), 1RM squat strength (strength) and thigh muscle cross-sectional area (TMCSA) in 38 women. A total body training group (TBTG; n =22) and an upper body training group (UBTG; n=18) and trained 3 days/wk for 6 months in a periodized fashion (repetitions varied between 8 and 12, rest intervals between sets varied between 45 and 90 secs). A 20-30 minute aerobic conditioning session followed each workout. Venous blood samples were obtained pre and post an acute resistance exercise test ([ARET] 6 sets of 10RM squats separated by 2 min rest periods) and MCSA was assessed via magnetic resonance imaging on three separate occasions during training (month 0 [T1] month 3 [T2] and month 6 [T3]. An ANOVA with repeated measures ($p \leq 0.05$) revealed significant training and interaction effects. Mean±SD: TBTG (strength (kg): T1=54±12 ,T2=63±11, T3=69±14); (MCSA (cm^2): T1=126±17, T2=129±15 , T3=133±14); UBTG (strength (kg): T1=52±10 ,T2=58±10, T3=59±9); (MCSA (cm^2): T1=123±18, T2=122±17 , T3=126±17). The T1 %ΔFT for ARET was significantly associated with T1 to T3 MCSA Δs ($r=0.35$). The ARET induced elevations in IGH, TT, and FT and training X pre-post ARET interactions suggest that concomitant with increases in strength and hypertrophy after chronic heavy resistance training are alterations in the hormonal milieu after acute resistance exercise. *DoD US Army Grant 17 95-C-5069 to WJK*

277 GROWTH HORMONE VARIANTS AND BIOACTIVITY IN RESPONSE TO HEAVY RESISTANCE EXERCISE IN WOMEN

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An awareness of hGH's polymorphism (over 15 variants identified) now exists but limited data are available as to the responses of various molecular variants to exercise. This study examined the effects of an acute heavy resistance exercise protocol ([HREP]; 6 sets of 10RM squats separated by 2 min rest periods) on the concentration, molecular size, immunoreactivity, and bioactivity of hGH in 22 untrained women (22±2yrs). Blood samples were obtained by venipuncture pre- and immediately post-HREP. Plasma fractionation by Sephacryl S-100HR column chromatography prior to measurement of hGH was employed to partition proteins and hGH variants into 3 size classes; fraction A (apparent MW >60 kd), fraction B(30-60 kd), and fraction C (<30 kd). Neat and fractionated samples were assayed for bioactive hGH concentration[i.e., two assays: the Nb2 lymphocyte proliferation assay and the tibial line bioassay in the hypox rat] and immunoreactive hGH concentrations via monoclonal RIA. Significant ($p \leq 0.05$) increases after HREP in hGH were observed for the RIA for the neat, and in the A and B fractions. Thus, post-exercise samples for RIA appeared to increase aggregation with either other hGH molecules or hGH binding proteins. The Nb2 bioassay demonstrated no changes in bioactivity of hGH after HREP. The tibial line bioassay results showed no exercise-induced changes in the total sample pool. However, closer study of the data revealed two sub-groups of responders post-exercise. Significant increases or decreases occurred when cortisol values were lower (C increase); higher (C decrease); IGF-1 values higher (B and C increases); lower (B and C decreases). Fraction A showed none of these responses. These results demonstrate that hGH molecular variants respond differentially based upon the assay used and the array of hormonal responses in the exercising subject. *DOD US Army DAMD 17-95-5069*

THE EFFECTS OF DIFFERENT TRAINING PROGRAMS ON UPPER BODY POWER IN WOMEN

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The purpose of this study was to compare the effects of 6 months of periodized, heavy-resistance, calisthenics/manual resistance (CMR), and aerobic training (AER) performed on 3 alternating days per week on upper body power in women. We examined the hypothesis that "explosive" strength/power (SP) resistance training (3- to 8-RM) would result in greater improvements in peak and mean upper body power than hypertrophy (H) resistance training (8- to 12-RM) in untrained women. Sixty women aged 23.3 (SD=3.9) years were randomly assigned to either the SP (n=17), H (n=18), CMR (n=14), or AER group (n=11). All women were tested pre- and post-training for one-repetition maximum bench press strength (1-RM BP) and bench-press-throw peak and mean power output using 30% of 1-RM. Rate of force development (RFD) of the bench-press-throw also was analyzed for comparison between groups. Results (means±SD) indicated that 1-RM BP (12±5 kg), peak power (68±40 W), mean power (8±8 W), and RFD (264±180 N/s) increased significantly ($p < 0.05$) in the SP group following training. Training resulted in increases in 1-RM BP (9±6 kg), peak power (47±44 W), and RFD (166±135 N/s) in the H group; and 1-RM BP (10±2 kg), peak power (57±23 W), and mean power (8±8) in the CMR group. Post-training values for 1-RM BP, peak power, mean power, and RFD were greater in the SP group than the H, CMR, and AER groups. These data indicate that explosive strength/power resistance training elicits superior upper body power and strength adaptations in women as compared to hypertrophy, calisthenics/manual resistance, and aerobic training.

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CIRCULATING CONCENTRATIONS OF GROWTH HORMONE AFTER RESISTANCE EXERCISE IN MEN AND WOMEN: A COMPARISON OF TWO ASSAY METHODS.

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Human growth hormone (hGH) is a pleiotropic peptide hormone that has many biological targets. It exists as a family of molecular variants. Because of this molecular heterogeneity, it is possible that not all detection methods for hGH would yield the same results. Strasburger et al. (JCEM, 1996) recently reported development of an "immunofunctional" ELISA that employs a monoclonal antibody specific for site 2 and a recombinant biotintylated GH binding protein specific for site 1 on the hGH molecule. Thus, this method detects only those hGH molecules capable of inducing receptor dimerization and subsequent signal transduction. Conceivably, this assay could yield results of greater biological relevance than those obtained using conventional RIAs. This study compared the immunoreactive (via a monoclonal $IRMA_{Nichols}$) vs. immunofunctional (via a $ELISA_{DSL}$) hGH concentrations pre and post resistance exercise (i.e. 6 sets of 10RM squats separated by 2 min rest intervals) in 8 men and 6 women. Both men (pre: 1.47 ng/ml vs. post: 25.0 ng/ml) and women (pre: 4.0 ng/ml vs. post: 25.4 ng/ml) demonstrated similar increases in immunoreactive hGH following exercise. Also, men (pre: 0.55 ng/ml vs. post: 11.66 ng/ml) and women (pre: 1.94 ng/ml vs. post: 10.41 ng/ml) demonstrated similar increases in immunofunctional hGH following exercise. The ratio of immunoreactive/immunofunctional hGH was similar for men and women after exercise (2.4 vs. 2.5, respectively). Post-exercise, but not pre-exercise, immunofunctional hGH was significantly ($p \leq 0.05$) lower than immunoreactive hGH for both men and women suggesting that monoclonal RIAs detect epitopes other than those located at sites 1 and 2. These data also suggest that the dramatic increase in hGH concentrations following exercise detected by monoclonal RIAs may not necessarily be translated into a biological outcome. These results have important implications for scientists who may be most concerned with the "bioactivity" rather

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The effects of resistance training on augmenting women's performance during a high-intensity military relevant manual materials handling task

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Abstract

This study evaluated the effects of two resistance training programs: (1) upper body training (UBT) and 2) total body training (TBT) on improving performance during a repetitive box lifting task (RBLT) and a 1 repetition maximum (1RM) box lift. The RBLT was designed to simulate a military relevant task and consisted of the maximum number of boxes (20.45 kg) that could be lifted from the floor to a height of 1.32 m within a 10 min period (subjects were required to move between two boxes 2.4 m apart between lifts). Forty-six women (23.6±3.9 yrs, 166±5.6 cm, 63.5±9.2 kg) were randomly divided into either a UBT group (n= 23) or a TBT group (n = 23) and trained for 3 months. The training was periodized by alternating the number of repetitions/sets over the 3 months from 12 to 8 (rest between sets ranged from 30 sec to 60 sec). A 20-30 min aerobic component was also performed by both groups. Results (mean±SD) were: 1RM (TBT: pre - 29.5±4.4 kg, post - 34.1±4.4 kg, 15.6% change; UBT: pre - 30.5±5.4 kg, post - 34.6±6.3, 13.4% change); RBLT (TBT: pre - 86.0±22.6 reps, post - 106.4±16.7 reps, 23.7% change; UBT: pre - 85.3±24.6 reps, post - 103.7±24.5 reps; 21.5% change). For the RBLT and 1RM box lift, an ANOVA with repeated measures revealed significant effects due to training ($p \leq 0.05$), but no group or interaction effects. These data indicate that a resistance training program targeted at higher repetitions and short rest periods results in improvements in physically demanding occupational tasks and also indicate that adaptations in the upper body appear to account for a greater proportion of these gains during an initial 3 month program in untrained young women. These data lend support for the implementation of resistance training programs for augmenting women's performance in the military.

1. Introduction

Success in military tactical environments, whether during war or peace-keeping missions, requires many military occupational specialties (MOSs) to perform high intensity manual materials handling tasks (e.g., such as the rapid displacement of food rations, medical supplies, or munitions). While it is recognized that men possess advantages (i.e., because of greater average size and strength) over women in performing these tasks, scant data are available on how women's performance in such tasks can be improved through resistance training interventions [4]. This remains an important question, as the US Army is currently evaluating the physical potential of women in an attempt to determine whether more physically demanding MOSs might become available to them. For training doctrine, it is essential to understand optimal training strategies that will serve to maximize the fitness and performance of women in "real-world" occupational tasks. Presently, organized physical

training in the military revolves mainly around generalized calisthenic-type exercises (i.e. push-ups, sit-ups, etc.). Paradoxical to this emphasis is research that demonstrates periodized resistance training to be the superior mode of training for eliciting strength and performance gains [2]. It is also unfortunate that the current Army Physical Fitness Test (i.e. push-ups, sit-ups, and 2-mile run) toward which the Army orients its physical training and also uses to assess "fitness" bears little resemblance to dynamic, functional occupational tasks that women are likely to encounter during a typical work day in the military.

Lifting and lifting and carrying tasks involving muscles of the chest and shoulder girdle have been identified as "limiting factors" that inhibit women in certain physically demanding jobs. When women are compared to men, the strength disparity is greater for the upper body than the lower body. Knapik et al.[1] reported the female/male ratio for isometric strength to be 0.60 for the upper body and 0.67 for the lower body. In light of these facts, one might propose that women could derive the most benefit from resistance training targeted specifically at upper body musculature. Thus, the purpose of the present study was to compare the effects of short-term upper body vs. total body resistance training on two physical performance tasks designed to mimic tasks that women might encounter during a routine work day in the US Army.

2. Materials and Methods

Subjects for this study were 46 civilian women volunteers who were medically screened and gave written informed consent prior to participation. Physical characteristics were as follows: 23.6±3.9 yrs, 166±5.6 cm, 63.5±9.2 kg. Subjects were tested for their one repetition maximum (1RM) i.e., the maximum load (kg) that could be lifted with correct form (i.e., squat style of lifting) in the maximum box lift. The maximum box lift consisted of lifting a metal box (0.47 m X 0.23 m X 0.31 m) from the floor to a height of 1.32 m. This height was specifically chosen at 1.32 m because it is also the height from the ground to a back end bed of an Army utility truck. Thus, this functional lifting task was one that a soldier would be likely to encounter during a typical work day. Spotters monitored lifting technique to safeguard against injury and mass was incrementally added to the box until the subject could no longer complete the lift. A minimum of 48 hours rest was given before the repetitive box lifting test (RBLT). The RBLT was designed to simulate a military relevant task and consisted of the maximum number of boxes (20.45 kg) that could be lifted from the floor to a height of 1.32 m within a 10 min period (subjects were required to move between two platforms 2.4 m apart between lifts). The test-retest reliability of this test is 0.97.

After baseline testing, all subjects were randomly placed into one of two training groups: 1) total body training (TBT) and 2) upper body training (UBT). The training programs by both groups consisted of a 12 week periodized resistance program with a short aerobic session conducted three alternating days per week [2]. The 12 weeks were broken into three, four-week mesocycles. The first four week mesocycle design consisted of 12 repetitions per set, 90 seconds rest between sets, and three sets per exercise; the second four week mesocycle of 10 repetitions per set, 90 seconds rest between sets of large muscle group and 60 seconds between small muscle group exercises; and the third four week mesocycle of 8 repetitions per set, 60 seconds rest between sets, and four sets per large muscle group exercise. Each subject was supervised by a trainer who prescribed the resistance used for each set, prepared the appropriate apparatus, spotted the subject, and monitored the rest periods. Repetitions were determined by each subject's 1RM capability and were closely monitored. Resistance was subtly increased in each exercise from one training session to the next according to the subject's capability, and was significantly increased concomitant with the reduction of repetitions from one mesocycle to the next.

The differentiation of design between the TBT and UBT was mostly an elimination of hip and leg exercises from the UBT program. The TBT program consisted of rudimentary large muscle group exercises for the total body, while the UBT incorporated the same upper body exercises with additional supplementary upper body exercises. Both groups followed the same periodized program design and did identical aerobic sessions. Examples of the exercise programs performed by both groups is shown below. A repeated measures analysis of variance was used to test for group, training and interaction differences. The significance level was chosen as $p \leq 0.05$.

Example training workouts of total body and upper body training programs

Total Body Training			Upper Body Training		
Exercise	Sets/Reps	Rest	Exercise	Sets/Reps	Rest
Squat	4x8	60 sec	Bench Press	4x8	60 sec
Leg Extension	3x8	30 sec	Seated Row	4x8	60 sec
Leg Curl	3x8	30 sec	Dumbbell Press	3x8	60 sec
Bench Press	4x8	60 sec	Lat Pulldown	3x8	60 sec
Seated Row	3x8	60 sec	Curl	3x8	30 sec
Heel Raise	3x8	30 sec	Tricep Pushdown	3x8	30 sec
Curl	3x8	30 sec	Sit-Up	3x25	60 sec
Tricep Pushdown	3x8	30 sec	Back Extension	3x8	30 sec
Sit-Up	3x25	60 sec			

3. Results and Discussion

Table I displays the mean±SD for the 1RM box lift and the RBLT for the UBT and TBT groups pre- and post-training. ANOVA with repeated measures revealed significant effects due to training ($p \leq 0.05$), but no group or interaction effects for both measures. Figure 2 illustrates the magnitude of the percentage change for the TBT and UBT groups in the 1 RM box lift and the RBLT from pre- to post-training.

Table I. Mean±SD for the 1 RM box lift and RBLT pre- to post training. * denotes significant ($p \leq 0.05$) training effects.

Variable	Pre-training (wk 0)	Post-training (wk 13)
1 RM box lift (kg)*		
TBT	29.5±4.4	34.1±4.4
UBT	30.5±5.4	34.6±6.3
RBLT (repetitions)*		
TBT	86.0±22.6	106.4±16.7
UBT	85.3±24.6	103.7±24.5

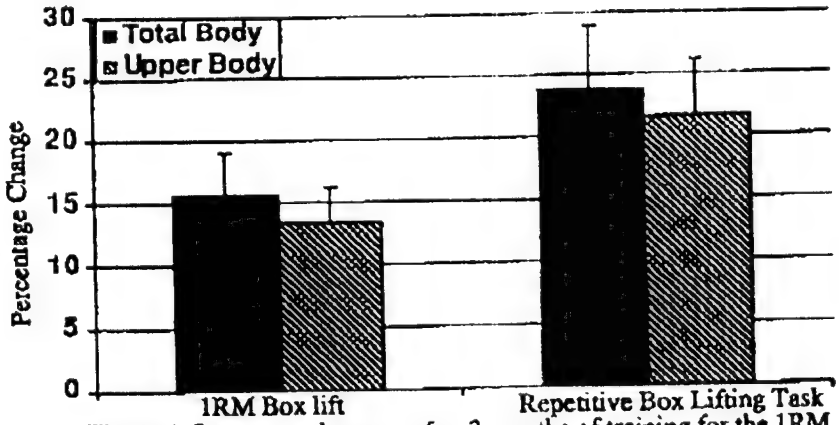

Figure 1. Percentage increase after 3 months of training for the 1RM box lift and repetitive box lift test. ANOVA revealed significance ($p \leq 0.05$) for training main effects for both measures.

Two salient findings emerge from this study: 1) upper and total body training groups exhibited changes of similar magnitude in the two performance tasks; and 2) the magnitude change for the RBLT was greater than for the 1 RM box lift (averaging 21.6% vs. 14.5%, respectively). While prior research has established that resistance training increases muscular size and strength, the majority of studies have examined the impact on athletic performance rather than occupational performance per se in women. These data extend previous resistance training studies in men that demonstrated improvements in occupational tasks.

These data indicate that short-term resistance training programs (< 3 months) result in significant adaptations in the upper body musculature of young women. The upper body adaptations appear to make greater contributions than the lower body in the performance of total body lifting tasks. The lifting height of 1.32 m in this study represents 80% of the mean height of women (i.e., approximately shoulder height). Therefore, lifting to this height requires substantial involvement of muscles surrounding the chest and shoulder girdle area. The upper body strength has been identified as a factor which limits women in physically demanding occupations. In the military, it would therefore seem prudent to target women's upper body for strength improvement. An emphasis on upper body strength development via resistance training during either basic or advanced individualized training (AIT) might ensure that more women enter their duty stations prepared for "heavy" and "very heavy" MOSs. Because of inherent body size differences between the sexes, it is unlikely that the average women can be trained to be stronger than the average physically trained man. A more realistic goal would be to train to meet the physical demands of the job regardless of sex. For example, resupply of a 155-mm Howitzer requires repetitive lifting of a projectile weighing 41 kg and is considered one of the most physically demanding tasks a field artillery soldier performs. As long as a women soldier's maximal lifting capability exceeded 41 kg, she would be able to effectively perform this task. The women's mean 1 RM box lift for this study after 3 months was ~34.3 kg, illustrating the need for further strength training or a heavier strength training program in order for these women to physically accomplish Howitzer loading. In a previous study, Sharp et al [3] reported significant improvements for men in the box lift (22.8%) and repetitive box lifting capacity (18.8%) for 18 men after 12 weeks of progressive resistance training. In contrast to the study by Sharp et al.[3], the present study employed an aerobic training component. Since RBLT was a 10-minute submaximal task, the aerobic system was heavily involved. In fact, in regression analysis, aerobic capacity was identified as a significant predictor of RBLT performance (unpublished data). TBT and UBT both performed identical aerobic programs as part of their training and if aerobic capacity were a major component of this test, this fact would explain similar improvements for the RBLT between TBT and UBT.

In summary, this study demonstrates that significant improvements in physically demanding occupationally tasks can be observed following only 12 weeks of periodized resistance training (light to moderate loads -12RM going to 8RM loads). However, adaptations in the upper body accounted for most of these early improvements in task performance. Further study will be needed to observe the effects of longer duration training and heavier programs in women. Ultimately, decisions will need to be made based on experimental data on women's ability to train for specific occupational tasks and not political or societal pressures based on perceptions of what they should do. This will allow for objective and fair decisions with respect to what role women can play in military scenarios.

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Prediction of military relevant occupational tasks in women from physical performance components

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Abstract

This study sought to determine through multiple regression analysis which measures were most predictive for a repetitive box lifting task (RBLT) and for a load bearing task (LBT) (i.e. 2 mile, 34.1 kg military rucksack carry) in 113 women (23±4 yrs, 165±7cm, 64±10 kg). The RBLT consisted of the maximum number of boxes (20.45 kg) that could be lifted from the floor to a height of 1.32 m within a 10 min period (subjects were required to move between two boxes 2.4 m apart between lifts). The LBT consisted of the minimum time to traverse 2 miles while carrying a 34.1 kg military style rucksack. Independent variables (IVs) included body mass, height, magnetic resonance imaging assessed leg cross-sectional area, muscular strength 1 RMs (squat, bench press, high pull, boxlift), lower body explosive power (mechanical power assessed via jump squats), muscular endurance (# of push ups in 2 min and # of squat repetitions at a controlled rate with a 45 kg load [squat endurance test]) and aerobic capacity assessed from a 2 mile run (2MR in secs). The mean±SD (range) for the RBLT (# of repetitions) was: 86±23 (20-159) and for the LBT (in seconds) was: 2054±340 (1307-3447). The following equations were generated ($p \leq 0.05$): RBLT (# of repetitions) = 57.4 + 0.2(peak jump power) + 0.4(# of push-ups in 2 min) + 0.15(# of repetitions during the squat endurance test) + 1.39(1RM boxlift in kg) - 0.04(2MR in secs) [R = 0.81; SEE = 14]; LBT (in seconds) = 1831 - 4.28(# of repetitions during the squat endurance test) + 0.95(2MR in seconds) - 13.4(body mass) [R = 0.73; SEE = 232]. The fact that the 2MR and squat endurance test entered into both equations illustrates their utility as potential predictors for successful military occupational performance. These data also suggest that women can augment their performance in physically demanding occupations by participating in conditioning programs targeting both muscular strength and endurance.

1. Introduction

As increasing numbers of physically demanding military occupational specialties (MOSs) continue to become available to women, it is essential to establish a complete understanding of what physical performance characteristics are most important for success of specific military relevant tasks. The ability to effectively lift loads and manage the tasks related to manual material handling are important to military operational success. In addition, the obvious need to demonstrate effective load bearing capabilities are essential to many military operational scenarios. It might be hypothesized that these two task have both muscular endurance and strength components, yet the relative contribution of each remains unknown.

Both material load handling and load bearing tasks are two occupational challenges that women can encounter in the military. These tasks are both physically demanding and have the potential for higher incidences of injury. The components of physical fitness which most contribute to successful performance of these tasks in women have not been fully examined [3]. In addition, the women who enter basic training are of varied physical

training background and physical fitness abilities. In order to gain a basic understanding about the physical demands which contribute to success in these two types of military relevant tasks, the relationships between these tasks with various characteristics of physical fitness need to be studied [1]. Such data would provide preliminary information as to the extent of physical training needed to meet the demands of these two military relevant tasks. Thus, training interventions could be planned and implemented that with time would allow greater soldier productivity. It was the purpose of this study to identify through simple and multiple regression analyses what physical fitness components would be of predictive value for two military relevant occupational tasks in women: 1) a repetitive box lifting task (RBLT) and 2) a endurance-based, load bearing task (LBT) (i.e., a 2 mile carry for time with a military style 34.1 kg rucksack).

2. Methods and Materials

The subjects for this investigation were 123 civilian women volunteers who were medically screened and gave written informed consent prior to their participation. Physical characteristics were as follows: 23±4 yrs, 165±7cm, 64±10 kg. The independent measures used in this study were: body mass (BM), height (HT), magnetic resonance imaging assessed thigh muscle cross-sectional area (TMCSA), one repetition maximal strength (1 RM) in the bench press (BP), squat (SQ), high pull (HP) and box lift (BL), push-up muscular endurance (PU), explosive jump power (JP), squat endurance (SE), and 2 mile run time (2MR).

Independent Variables

Thigh muscle cross-sectional area (TMCSA). Thigh muscle cross-sectional area was assessed for the dominant leg using a MRI 0.5-Tesla super conduction magnet (Picker International Inc., Highland Heights, OH) with MR6B software. Tissue CSA was obtained by displaying the images through Maxitron displayer and Adobe program and using the MacIntosh NIH 1.55.20A Image Analysis computer program.

1RM strength measures. One RM strength measures were assessed with the use of The Plyometric Power System (PPS). The PPS was specially designed to accurately collect strength and power data and to safeguard against injury by using a braking system to prevent all falls. For the *1RM squat*, the subject was required to descend into a parallel squat position by flexing the knees and hips until the trochanter head of the femur reached the same plane as the superior border of the patella. For the *1RM bench press*, the subject was required to lower the bar until it touched the chest, and lift the bar back to the straight-arm position. For the *1-RM High Pull* , the subject stood upright with arms extended at the sides of the body and the feet positioned so that the instep of each foot was directly under the bar. The subject then extended the hips powerfully to full extension, rose onto the toes, shrugged the shoulders, and pulled the bar using the entire body movement to the medial clavicular height. The *1-RM Box Lift* required the subject to lift a metal box (0.47 m X 0.23 m X 0.31 m) from the floor to a height of 1.32 m. Upon failing an attempt on any of the 1RM tests, the subject was given a final attempt with a weight lighter than had been used in the failed attempt, but more than the highest successful attempt.

Muscular endurance and aerobic capacity. The maximum number of push-ups that could be correctly performed in two minutes was used to assess upper body muscular endurance. The minimum time required to traverse 2 miles was used to assess aerobic capacity. Both of these measures were tested according to guidelines and procedures given in the Army physical fitness training manual (FM 21-20).

Squat endurance test. The squat endurance test required the repetitive squatting with an absolute load of 45.36 kg placed on the barbell system of the PPS which was lifted over a specific distance of 0.36 m per repetition and at a rate of 37.5 repetitions per minute (0.625 repetitions per second). These specifications were employed to allow for an external power output of 100 watts during the test. The total number of repetitions that the subject performed was used for analysis.

Lower Body Explosive Power. To assess lower body explosive power, subjects performed an explosive squat jump lift using the PPS interfaced to a computer for data acquisition. The subject's previously determined 1-RM squat load was used to calculate a 30% of 1 RM intensity that was used in the squat jump test. The squat jump required the subject to perform a parallel squat and upon reaching the bottom position of the lift, to explosively extend the hips and knees accelerating the barbell mass upward with maximum power.

Militarily relevant occupational tasks dependent variables

Repetitive box lift task (RBLT): The RBLT consisted of the repetitive lifting of two 20.45 kg metal boxes placed onto two platforms 1.32m in height (to simulate the height of a military truck) and 2.4m apart. The subject moved at a volitional pace between one platform and the other to lift the box adjacent to the platform to the top of that platform. The object of the test was to lift as many boxes as possible in 10 min., with the performance measured by the total number boxes lifted.

Load bearing task (LBT) : The LBT consisted of the carrying a 34.1 kg backpack (termed rucksack) for a 2-mile distance on an all-weather 400m track. The rucksack consisted of an external frame with the load properly positioned within the backpack. Upon command, the subject moved as fast as they could to cover the 2-mile distance, with the performance measured in seconds.

Simple and stepwise multiple regression analyses were used to determine relationships between and among variables. The significance level was chosen as $p \leq 0.05$.

3. Results and Discussion

Table 1 lists the descriptive data for the various tests with the 25th, 50th and 75th percentiles presented for all variables. These variables were selected because they represent a spectrum of physical fitness components that influence physical task performance. An attempt was made to select tests that assessed upper and lower body muscular strength and endurance as well as aerobic capacity. Depending on the variable the sample size ranged from 113 to 123. This sample population of healthy women with no previous history of resistance training demonstrated a wide range of fitness capabilities. For some variables (e.g., push-ups and squat endurance) some subjects failed to complete a successful repetition, thus demonstrating a high discriminating ability for the these tests.

Table 1. Mean±SD (range) and the 25th, 50th, and 75th percentile values for all variables.

Variable	n	Mean±SD (range)	25 th percentile	50th percentile	75th percentile
Height (cm)	122	166±7 (145-184)	162	166	169
Weight (kg)	123	64±10 (43-106)	57	62	70
TMCSA (cm^2)	122	122±17 (89-183)	111	120	132
Bench Press (kg)	123	32±7 (17-58)	26	31	35
Squat (kg)	123	52±12 (17-88)	44	52	58
High Pull (kg)	121	33±6 (15-54)	29	32	36
Maximal Box lift (kg)	121	30±5 (21-48)	27	30	33
Push-ups (reps)	120	20±13 (0-57)	10	17	28
Squat Endurance (reps)	116	19±14 (0-95)	8	16	24
Jump Power (watts)	116	1623±323 (875-2868)	1390	1587	1797
Two mile run (secs)	120	1213±231 (830-2040)	1358	1191	1043
Rucksack run (secs)	113	2054±337 (1307-3447)	2267	2025	1850
Repetitive Box lift (reps)	113	86±23 (20-159)	69	85	104

TMCSA = leg muscle cross-sectional area; cm = centimeters; kg = kilograms; reps = repetitions; secs = seconds.

Table 2 displays the correlational matrix among all variables. All of the independent variables significantly correlated with the 2 dependent variables (e.g., RBLT and LBT). The two mile run time yielded the highest correlation (r = -0.61 for the RBLT and 0.60 for the

LBT). Still, other factors contribute to these task performances as only about 36% of the shared variance is explained. It is interesting to note that the test battery used was diverse and represented different physical requirements of the neuromuscular system as noted by the low to moderate relationships for multicolinearity of the tests performed.

TABLE 2. Correlational matrix among all variables.

	BP	BL	TCSA	HP	HT	JP	PU	SE	SQ	2MR	BM	RBLT	LBT
BP	**1.00**	**0.58**	**0.50**	**0.71**	0.09	**0.50**	**0.48**	**0.48**	**0.57**	**-0.28**	**0.24**	**0.56**	**-0.48**
BL	**0.58**	**1.00**	**0.53**	**0.62**	**0.46**	**0.66**	0.10	**0.43**	**0.58**	-0.03	**0.53**	**0.54**	**-0.37**
TCSA	**0.50**	**0.53**	**1.00**	**0.60**	**0.24**	**0.74**	-0.03	**0.50**	**0.61**	0.00	**0.60**	**0.41**	**-0.31**
HP	**0.71**	**0.62**	**0.61**	**1.00**	**0.20**	**0.66**	**0.20**	**0.52**	**0.58**	**-0.18**	**0.32**	**0.52**	**-0.42**
HT	0.09	**0.46**	**0.29**	**0.20**	**1.00**	**0.44**	**-0.35**	**0.22**	0.04	0.01	**0.54**	**0.22**	**-0.27**
JP	**0.50**	**0.66**	**0.74**	**0.66**	**0.44**	**1.00**	-0.10	**0.59**	**0.64**	0.00	**0.67**	**0.47**	**-0.35**
PU	**0.48**	0.10	-0.03	**0.20**	**-0.35**	-0.01	**1.00**	**0.24**	**0.28**	**-0.52**	**-0.39**	**0.45**	**0.26**
SE	**0.48**	**0.43**	**0.50**	**0.52**	**0.22**	**0.59**	**0.24**	**1.00**	**0.59**	**-0.32**	**0.17**	**0.55**	**-0.46**
SQ	**0.57**	**0.58**	**0.61**	**0.58**	**0.04**	**0.69**	**0.28**	**0.59**	**1.00**	-0.16	**0.26**	**0.48**	**-0.27**
2MR	**-0.28**	-0.03	0.00	**-0.18**	0.01	0.00	**-0.52**	**-0.32**	**-0.16**	**1.00**	**0.41**	**-0.54**	**0.60**
BM	**0.24**	**0.53**	**0.60**	**0.32**	**0.54**	**0.67**	**-0.39**	0.17	**0.26**	**0.41**	**1.00**	**0.19**	**-0.19**
RBLT	**0.56**	**0.54**	**0.41**	**0.52**	**0.20**	**0.47**	**0.45**	**0.55**	**0.48**	**-0.54**	**0.19**	**1.00**	**-0.61**
LBT	**-0.48**	**-0.37**	**-0.31**	**-0.42**	**-0.27**	**-0.35**	**-0.26**	**-0.46**	**-0.27**	**0.60**	**-0.19**	**-0.61**	**1.00**

Bold indicates significance of $p \leq 0.05$. KEY: BP: 1-RM bench press (kg), BL: 1-RM box lift (kg), TCSA: Thigh cross-sectional area (cm) , HP: 1-RM high pull (kg), HT: Height (cm), JP: Jump power (W), PU: Push ups, SE: Squat endurance, SQ: 1-RM squat (kg), 2MR: 2-Mile run time, BM: Body mass (kg), RBL: Repetitive box lift, LBT: load bearing task; (i.e. 2-Mile rucksack carry)

Table 3 gives the regression equations for the RBLT and the LBT. For the RBLT, explosive jump power, push-ups, the squat endurance test, 1RM box lift and the two mile run time entered into the equation. For the LBT, the squat endurance test, the two mile run time and body mass entered into the equations.

TABLE 3. Regression equations for repetitive box lifting task (RBLT) and load bearing task (LBT).

Variable	Regression Equation	R	R^2	SEE
RBLT (reps)	57.4 + 0.2(JP) + 0.4(PU) + 0.15(SE) + 1.39(BL) - 0.04(TMR)	0.81	0.65	14
LBT (secs)	1831 - 4.28(SE) + 0.95(TMR) - 13.4 (BM)	0.73	0.53	232

In summary, the final equations explained approximately 65% of the variance for the RBLT and 53% of the variance for the LBT. The standard errors of estimates were 14 repetitions for the RBLT and 232 seconds for the LBT. The squat endurance tests and the timed 2 mile run entered into both equations. Thus, the importance of aerobic capacity and local muscular endurance were vital for both tasks. Task specific strength may also contribute to performance ability [2]. Surprisingly, the physical components measured in this study do not completely explain these two military-relevant task performances. Thus, other tests and/or factors (e.g., psychological) may need to be explored to better predict performance in untrained women. These two tasks are complex in their performance strategies, contributing physiological systems, psychological demands, and biomechanical techniques. Finally, high degrees of certainty for prediction of complex task performance in untrained women may not be possible using a battery of simple physical fitness tests.

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HYPERTROPHY OF THE UPPER AND LOWER BODY MUSCULATURE IN WOMEN FOLLOWING 6 MONTHS OF PERIODIZED HEAVY RESISTANCE TRAINING.

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INTRODUCTION

The extent and time-course in which previously untrained women are able to exhibit muscle enlargement (i.e. hypertrophy) of their upper and lower body musculature has not been firmly established, particularly following long term (> 3 months) periodized training. Presently, more data is needed regarding concomitant upper and lower body musculature adaptations in women after periodized resistance training regimens. This study compared the effects of 4 different periodized heavy resistance programs on upper arm and mid-thigh muscle hypertrophy assessed by magnetic resonance imaging (MRI).

METHODS

74 women (23±4 yrs, 165±7 cm, 64±10 kg, 25±6 %BF) were randomly divided into 1 of 4 heavy resistance training programs: total body strength/power (TBSP, n=17), total body strength/local muscular endurance (TBSLME, n=19), upper body strength/power (UBSP, n=20) and upper body strength/local muscular endurance (UBSLME, n=18) and trained for 24 wks. The programs were divided into two 12-wk macrocycles, each consisting of three mesocycles performed 3 days/week. The strength/ power (S/P) groups were delineated from the strength/local muscular endurance (S/LME) groups by having the S/P groups perform sets at heavier intensities and longer rest periods (see Table 1). When possible, the S/P groups performed repetitions in an explosive-type fashion The total body groups performed the following exercises: squat, leg extension and curl, dumbbell incline press, chest fly, front pull down, dumbbell row, and rotational crunch, while the upper body groups performed: bench press, seated row, dumbbell press, lat pull down, EZ curl, tricep push down, incline sit-up, and back extension. Each workout concluded with 20-35 minutes of aerobic exercise.

Table 1. Sets, repetition maximum (RM) loads and rest periods between sets for the 2 strength/power (S/P) and the 2 strength/local muscular endurance (S/T) groups.

	First Half of Macrocycle								
	MESOCYCLE 1 (3 wks)			MESOCYCLE 2 (6 wks)			MESOCYCLE 3 (3 wks)		
	SETS	LOAD	REST	SETS	LOAD	REST	SETS	LOAD	REST
S/P	3	8 RM	120 S	3	5-8 RM	120 S	3	3-6 RM	120 S
S/LME	3	12 RM	30-90 S	3	10 RM	30-90 S	3	8 RM	30-60S

Magnetic resonance imaging (*MRI*) . The muscle cross-sectional areas (MCSAs) of the midthigh (TMCSA) and mid upper arm (AMCSA) were measured pre-training (T1), mid-training (T2), and post-training (T3) by MRI using a 0.5 Tesla Picker Vista MR with MR6B software. The dominant limbs were used for the investigation. Tissue CSA was obtained by displaying the images through Maxitron displayer and Adobe program, and using the NIH 1.55.20A Image Analysis pixel counting program. An ANOVA with repeated measures using training group and training (T1, T2, & T3) as main effects determined significant difference ($p \leq 0.05$) for TMCSA and AMCSA. Test-retest reliability for the MRI was $R > 0.96$.

RESULTS

Table 2 shows the mean±SD for arm and thigh MCSAs throughout the training. Overall, all 4 groups showed dramatic increases in AMCSA, with mean group %Δs ranging from 13 to 20%. Figure 1 shows the actual CSA image for a subject that demonstrated a striking 34% increase in her AMCSA. All groups experienced significant increases from T1 to T2 and from T2 to T3. For 3 out of the 4 groups, the degree of hypertrophy from T2 to T3 was less than that observed from T1 to T2. As expected, only the total body groups experienced overall increases

in TMCSA (9.4% and 6.9% for the TBSP and TBS/LME groups, respectively.) Similar to the upper body, the lower body also demonstrated increases from T1 to T2 and from T2 to T3, and this hypertrophy appeared slightly greater from T2 to T3. There was not a significant correlation (r = 0.16) in %Δ between arm and thigh MSCA for the total body groups.

Table 2. Mean±SD for MRI changes in AMCSA and TMCSA throughout training.

Groups	T1	T2	T3	T1 to T2 %Δ	T2 to T3 %Δ	T1 to T3 %Δ
TBSP						
AMCSA	33.2±4.2^{A}	35.2±4.1^{A}	37.5±4.5^{A}	*6.6±7.2**	*6.6±3.2**	*13.4±6.7**
TMCSA	123.0±15.8^{A}	128.4±16.3^{A}	134.3±16.1^{A}	*4.5±4.3**	*4.8±3.5**	*9.4±4.1**
TBSLME						
AMCSA	32.3±5.7^{A}	36.1±4.5^{A}	37.6±5.0^{A}	*12.9±10.8**	*4.3±5.3**	*17.5±9.4**
TMCSA	124.7±15.7^{A}	127.5±12.6^{A}	132.9±14.5^{A}	*2.7±4.3**	*4.2±3.4**	*6.9±4.3**
UBSP						
AMCSA	32.0±3.8^{A}	35.7±4.7^{A}	38.4±4.4^{A}	*11.7±5.6**	*7.8±6.1**	*20.4±8.7**
TMCSA	122.3±17.5^{A}	120.1±17.9^{B}	123.6±15.0^{B}	*-1.7±4.2*	*3.3±4.7**	*1.5±4.6*
UBSLME						
AMCSA	32.3±5.3^{A}	36.6±5.8^{A}	38.5±7.5^{A}	*13.4±8.5**	*5.2±8.4**	*19.0±10.3**
TMCSA	123.4±17.4^{A}	121.7±16.7^{B}	127.1±16.3^{C}	*-2.0 ±4.9*	*4.7±4.5**	*2.4±3.2*

* Denotes statistical difference ($p \leq 0.05$). Letters denote group comparisons via post-hoc analysis within training timepoint. Similar letters denote statistical similarity, while different letters denote statistical difference.

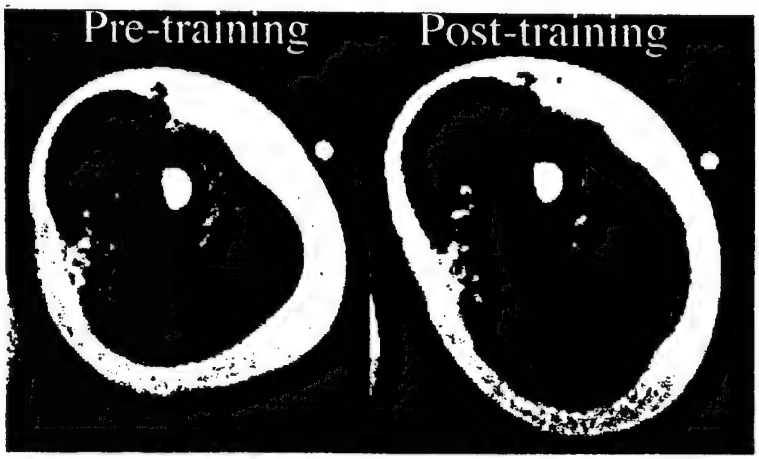

Figure 1. MRI of the AMCSA of subject #40 pre- and post-training showing a 34% increase.

DISCUSSION

The periodized heavy resistance training model employed in this study proved effective for eliciting hypertrophic adaptations in upper and lower body musculature in previously untrained women. A plateau (i.e. no significant change over time) was not observed in the training paradigm as significant increases in size of muscle tissue were apparent during the latter half of the study (T2 to T3).While neural factors are thought to make the major contribution to strength and power gains during short-term resistance training, an increasing awareness is recognized concerning adaptations intrinsic to muscle tissue. Muscle tissue can enhance strength and power capabilities by several means including alteration of the proportion of contractile/non-contractile proteins, myofibrillar isoform modifications, and muscle fiber and tissue hypertrophy. The MCSA of the upper arm in women appears very responsive to resistance training. Although direct comparisons cannot be made, it seems rather clear that the arm hypertrophied more rapidly and to a greater extent than did the thigh (Chilibeck et al. 1998). Interestingly, there was no correlation between hypertrophy between the arms and legs. This would seem to indicate that there may be regional muscle tissue differences in the responsiveness to the stimulus of resistance training.

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TESTOSTERONE CONCENTRATIONS IN WOMEN: RELATIONSHIP TO THE TRAINABILITY OF NEUROMUSCULAR PERFORMANCE

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INTRODUCTION

Androgens are known to positively impact nerve and muscle tissue. This effect can be beneficial in terms of neuromuscular performance. While testosterone (TEST) concentrations are 10-20 times greater in men than women, TEST is also anabolically potent in women. Clinical case studies involving female to male transsexuals have reported striking masculinizing effects when androgens are administered (Vague et al. 1984). In addition, TEST administration to female rats transforms muscle enzyme characteristics toward a more "male-like" glycolytic profile. A reasonable question that emerges from these data is whether TEST can serve as a "marker of trainability" in women. Supporting this contention, Häkkinen et al. 1990 reported significant correlations between Δs in basal TEST and Δs in force production (r = 0.78-0.95) after 16 wks of resistance training in 8 women. The study examined two hypotheses: 1) that TEST concentrations (both total and free) in women would be associated with muscular strength, power and hypertrophic parameters and 2) that changes in TEST concentrations during training would be correlated with the "trainability" of these measures after resistance training.

METHODS

One-hundred and seventeen previously untrained women (23±4 yrs; 166±7 cm; 65±9 kg) were initially tested on the following variables: one repetition maximum (1RM) squat strength, bilateral isometric leg extension force (leg force), explosive peak and mean power capacity via squat jumps at 30% 1RM squat (PP & MP), rate of force development during the jump squat (RFD), and upper thigh muscle cross-sectional area (TMCSA). The 1RM squat and subsequent power generation via squat jumps was performed on The Plyometric Power Machine; specially designed for safe and accurate measurement of strength and power. Bone-free mid-thigh muscle cross-sectional area (MCSA) was determined by magnetic resonance imaging. Morning fasted blood was obtained via venipuncture before and after 3 months of heavy resistance training (at the same time of day) and assessed by radioimmunoassay for hormonal concentrations of total and free testosterone (TT & FT).

Following baseline testing, 46 subjects were randomly assigned to either a total body strength/power (TBSP, n=22) or a total body strength/local muscular endurance (TBSLME, n = 24) group. Both groups performed periodized resistance training 3X/wk for 3 months. The delineation between the groups was in the relative intensity in which the sets were performed, duration of rest between sets and the velocity of the muscle actions. The TBSP group performed sets ranging from 3-8 RM with 120 s rest between sets, while the performed sets at 8-12 RM loads with 30-90 s rest between sets. When possible, the TBSP performed repetitions in an explosive-type fashion. The groups performed the following exercises: squat, leg extension and curl, dumbbell incline press, chest fly, front pull down, dumbbell row, and rotational crunch. Each workout concluded with 20-35 minutes of aerobic exercise.

RESULTS

In the static sample of 117 women, basal TT concentrations were correlated with mean power and the RFD during explosive squat jumps, while basal FT was correlated with 1RM squat strength, isometric leg extension force, explosive jump squat peak and mean power, and RFD (Table 1). Following 3 months of periodized training both groups exhibited significant increases for all neuromuscular performance parameters, while no differences were observed for basal concentrations of TT and FT (Table 2). There were no significant relationships between pre-training basal concentrations of TT and FT and neuromuscular performance (the

correlation between FT and %Δ MP was r = 0.29; p = 0.06). There was a significant correlation between ΔTT concentration and %ΔPP (r = 0.34) and ΔFT and % Δforce (r = 0.35).

Table 1. Static correlations between neuromuscular performance parameters and basal testosterone concentrations. * $p \leq 0.05$.

	1RM Squat (kg)	Force (N)	PP (W)	MP (W)	RFD ($N \bullet S^{-1}$)	TMCSA (cm^2)
TT (nmol•L)	r = 0.16	r = 0.09	r = 0.13	r = 0.21*	r = 0.24*	r = 0.11
FT (nmol•L)	r = 0.24*	r = 0.25*	r = 0.21*	r = 0.29*	r = 0.21*	r = 0.17

Table 2. Effects of training on dependent variables. * $p \leq 0.05$.

	1RM Squat (kg)	Force (N)	PP (W)	MP (W)	RFD ($N \bullet S^{-1}$)	TMCSA (cm^2)	TT (nmol•L)	FT (nmol•L)
Pre	52±11	76±16	1699±289	846±107	3042±1211	122±15	1.38±0.8	6.32±3.5
Post	64±11*	90±17*	1806±296*	896±90*	2556±849*	126±15*	1.33±0.8	6.44±4.6

Table 3. Correlations between the %Δ in neuromuscular performance parameters and the change in basal TEST concentrations following 3 months of heavy resistance training. * $p \leq 0.05$.

	%Δ 1RM Squat	%Δ Force	%Δ PP	%Δ MP	%Δ RFD	%Δ TMCSA
TT (nmol•L)	r = 0.02	r = -0.07	r = -0.24	r = 0.02	r = -0.21	r = 0.04
FT (nmol•L)	r = 0.08	r = -0.15	r = -0.12	r = 0.29	r = -0.12	r = -0.14
Δ TT (nmol•L)	r = 0.20	r = 0.23	r = 0.34*	r = 0.01	r = 0.30	r = 0.21
Δ FT (nmol•L)	r = 0.00	r = 0.35*	r = 0.20	r = 0.10	r = 0.10	r = 0.24

DISCUSSION

In 117 previously untrained women significant correlations were found between basal concentrations of FT and squat strength, leg isometric force production, explosive jump power, and the rate of force development during explosive jumps. In contrast, the only significant correlation with TT was with the mean power parameter. This finding illustrates the utility of employing a measure of FT (i.e. biologically available TEST) over the measurement of TT. The majority of TT circulates in the blood bound mainly to either albumin or sex-hormone binding globulin. It is generally thought that the TEST which circulates unbound (i.e. free) is able to traverse the capillary endothelium and penetrate the cell to transduce a biological signal. Our data would indicate that FT is more associated with acute neuromuscular performance than TT. While TEST is usually identified with longer-term genomic effects, some data suggests that TEST may also potentiate rapid effects on neural activation and recruitment of muscle fibers (Sachs et al. 1988). The association between Δs in TT and FT and %Δs in neuromuscular performance was tenuous. It is interesting to note, that of the correlations which were significant with training (i.e. ΔTT and %ΔPP & ΔFT and %Δ Force), none were found for hypertrophy. These data may suggest that TEST impacts neural factors associated with training-induced increased muscle activation more so than tissue growth per se during short-term training. We conclude that TEST concentrations do have physiological relevance in women with regard to neuromuscular performance.

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STRENGTH DEVELOPMENT IN UNTRAINED WOMEN DURING 6 MONTHS OF PERIODIZED HEAVY RESISTANCE TRAINING

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INTRODUCTION

It is well known that optimal resistance training programs incorporate periodized models. Upper and lower body strength responses of untrained young women to periodized programs are less understood, particularly following longer term (i.e., 24 wk) training programs (Chilibeck et al. 1998). This study compared the effects of 2 upper body and 2 total body periodized heavy resistance programs on lower and upper body maximal strength.

METHODS

Training Programs. Seventy-four women (23±4 yrs, 165±7 cm, 64±10 kg, 25±6 %BF) were randomly divided into 1 of 4 heavy resistance training programs: total body strength/power (TBS/P, n = 17), total body strength/local muscular endurance (TBS/LME, n = 19), upper body strength/power (UBS/P, n = 20) and upper body strength/ local muscular endurance (UBS/LME, n = 18) and trained for 24 wks. The programs were divided into two 12-wk macrocycles, performed 3 days/week on alternating days. The strength/power (S/P) groups were delineated from the strength/local muscular endurance (S/LME) groups by having the SP groups perform sets at heavier intensities and longer rest periods (see Table 1) The total body groups (TB) performed the following exercises: squat, leg extension and curl, dumbbell incline press, chest fly, front pull down, dumbbell row, and rotational crunch, while the upper body groups (UB) performed: bench press, seated row, dumbbell press, lat pull down, EZ curl, tricep push down, incline sit-up, and back extension. Each workout concluded with 20-35 minutes of aerobic exercise.

Table 1. Sets, repetition maximum (RM) loads and rest periods between sets for the 2 strength/power (S/P) and the 2 strength/local muscular endurance (S/LME) groups for the first half macrocycle.

	First Half of Macrocycle								
	MESOCYCLE 1 (3 wks)			MESOCYCLE 2 (6 wks)			MESOCYCLE 3 (3 wks)		
	SETS	LOAD	REST	SETS	LOAD	REST	SETS	LOAD	REST
S/P	3	8 RM	120 S	3	5-8 RM	120 S	3	3-6 RM	120 S
S/LME	3	12 RM	30-90 S	3	10 RM	30-90 S	3	8 RM	30-60S

Strength assessment. One repetition maximum (1RMs) were determined for the squat (SQ), bench press (BP), and high pull (HP). All testing was performed on the Plyometric Power System. This system allows for accurate and safe measurment for strength and power

For the SQ the subject descended with a loaded bar on the upper back into a parallel squat position by flexing the knees and hips until the trochanter head of the femur reached the same horizontal plane as the superior border of the patella; then ascended to the upright starting position while maintaining proper position of the back throughout the lift. For the BP, the subject assumed a straight-arm position with a loaded bar, lowered the bar until it touched the chest and lifted the bar back to the straight-arm position, without moving the feet and/or raising the buttocks from the bench during the lift, or bouncing the bar off of the chest. For the HP, the subject assumed the pull position with the knees and hips flexed with the bar positioned at knee height, extended the hips powerfully to full extension, rose onto the toes, shrugged the shoulders, and pulled the bar to medial clavicular height. An unsuccessful attempt was failure of the bar to achieve height of a standing subject's medial clavical.

RESULTS

Table 1 shows the 1 RM values for the 4 training groups at T1, T2, and T3. Significant main effects for training existed for all 1 RM strength measures (T1<T2<T3). All groups, except UBS/P, demonstrated significant increases in 1 RM SQ at T2 At T2, the total body groups increased 1RM SQ strength (25%), while the upper body strength group increased 12%. At T2, both total body groups demonstrated greater squat strength than both upper body groups. From T2 to T3, the total body groups exhibited further gains (12%). Total body groups increased 1 RM SQ strength 40%, about three times the gains observed in upper body training groups. All groups increased BP strength from T1 to T2 (14 to 20%) and from T2 to T3 (12%). The total body power group demonstrated the greatest increase in BP values at T2 (20%) and T3 (36%). Significant main effects for timepoints and interaction effects were apparent for the HP. Only the total body power group demonstrated increases for the HP from T1 to T2 (17%) and from T2 to T3 (7%). The total body strength group significantly increased from T1 to T3 (11%). Maximal HP strength was unaffected in the upper body groups. By T2 and persisting at T3, the total body power groups demonstrated greater 1RM HP strength than the other groups.

Table 2. Strength 1RM changes through 6 months of periodized heavy resistance training

Training Group	T1	T2	T3	T1 to T2 % DIFF	T2 TO T3 % DIFF	T1 TO T3 % DIFF
TBS/P						
Squat	53.0±12.3 ^{A}	65.3±10.8 ^{A}	73.0±10.3 ^{A}	*25.2±13.6**	*12.7±8.9**	*41.2±20.0**
Bench pr	35.4±7.3 ^{A}	42.3±9.5 ^{A}	47.5±8.5 ^{A}	*19.8±14.4**	*13.8±13.3**	*35.6±17.2**
High pull	33.5±7.4 ^{A}	38.7±7.2 ^{A}	41.0±6.2 ^{A}	*16.5±9.3**	*6.9±9.6**	*24.4±13.3**
TBS/LME						
Squat	52.3±11.0 ^{A}	63.5±11.8 ^{A}	70.1±14.2 ^{A}	*23.8±23.8**	*10.5±7.1**	*37.3±31.8**
Bench pr	32.6±9.0 ^{B}	37.3±9.0 ^{B}	41.1±8.8 ^{B}	*15.8±12.2**	*11.2±11.2**	*29.0±21.0**
High pull	32.0±5.2 ^{A}	33.5±5.8 ^{B}	35.1±5.7 ^{B}	*4.7±6.3*	*5.8±14.0*	*10.6±14.5**
UBS/P						
Squat	54.0±11.6 ^{A}	55.5±10.2 ^{B}	58.9±10.3 ^{B}	*4.0±11.8*	*6.7±9.0*	*11.0±16.2**
Bench pr	33.5±6.7 ^{A,B}	38.6±6.3 ^{B}	43.1±6.3 ^{B}	*16.4±11.0**	*12.3±9.8**	*30.8±17.4**
High pull	33.1±4.5 ^{A}	33.6±5.8 ^{B}	35.0±5.7 ^{B}	*1.4±8.7*	*4.7±8.8*	*5.9±10.6*
UBS/LME						
Squat	52.2±9.6 ^{A}	58.0±9.5 ^{B}	59.4±8.9 ^{B}	*11.6±7.5**	*3.1±9.7*	*15.0±13.6**
Bench pr	34.3±7.8 ^{A,B}	38.9±8.5 ^{B}	43.5±9.1 ^{B}	*14.0±8.8**	*12.3±9.9**	*28.4±19.0**
High pull	33.4±5.2 ^{A}	33.1±6.7 ^{B}	34.7±5.4 ^{B}	*-1.5±9.5*	*6.9±13.9*	*4.4±9.9*

*Denotes statistical difference ($p \leq 0.05$) from previous timepoint indicated. Letters denote group comparisons via post-hoc analysis within training timepoint. Identical letters denote statistical similarity, while different letters denote statistical difference

DISCUSSION

The periodized heavy resistance training model employed in this study proved effective for eliciting significant strength gains throughout 6 month programs. As expected, the total body training groups showed much greater increases in the 1RM squat than the other two groups. However, a salient finding which emerged was that both upper body training groups demonstrated significant gains in SQ strength after 24 wks of training. It is hypothesized that the upper body contribution to the 1RM SQ is related to the structural support aiding the carriage of the bar during maximal slow velocity squat movements. Despite the fact that the prime movements tested by these lifts are of the lower body, the synergistic roles of the shoulder girdle and torso during a 1RM SQ play an important role throughout the eccentric and concentric phases of the lift especially in women with no previous experience in strength training. The fact that the upper body groups increased in the SQ but not the HP suggests that the role of the lower extremity muscles is also rather important in a maximal titak pulling movement, although to a lesser degree than in a maximal squat lift movement. In conclusion, previously untrained women can continue to demonstrate gains in both upper and lower body strength following 6 months of periodized resistance training. *Supported by DOD US Army DAMD 17-95-5069*

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THE EFFECTS OF A LOW-VOLUME PROGRESSIVE RESISTANCE EXERCISE PROGRAM VERSUS A HIGH-VOLUME PERIODIZED RESISTANCE EXERCISE PROGRAM ON MUSCULAR PERFORMANCE IN WOMEN

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INTRODUCTION

Studies examining the effect of training volume and intensity during resistance training on performance gains have met with conflicting results. Some investigations show no difference between high and low volume training programs, while others demonstrate a significant increase in performance in the high volume programs. Often these investigations are of a short duration and use untrained subjects. These two factors are very important when evaluating a resistance training study, as performance gains in untrained subjects are primarily due to neurologic adaptations that occur to the greatest extent during the first six to ten weeks of training (Häkkinen 1994). After this time, continued strength gains occur at a slower rate and are due mainly to muscle hypertrophy. Therefore the ability of a resistance training program to make continued performance gains after the initial training period of adaptation may be very different from early in the training period. A second factor involved in designing a resistance training program is variation of the program. A progressive resistance exercise program involves keeping the number of repetitions performed constant and increasing the absolute intensity of the load as the subjects strength increases. Alternatively, periodization involves systematically changing the volume and intensity of the resistance over time. Periodization attempts to continually place new physiological stresses on the muscle to stimulate muscle growth and maximize neurologic adaptations. Data from studies comparing the two generally favor the periodized resistance program (Willoughby 1993). Despite these findings, current recommendations by organizations such as ACSM for resistance exercise programs promote a low-volume, progressive resistance exercise program. The purpose of this study was to compare the effects of a low-volume, progressive resistance exercise program to a high-volume periodized resistance exercise program in eliciting changes in muscular strength, endurance, power and hormonal changes in untrained women.

METHODS

34 healthy untrained women were randomly assigned to one of three groups: a control group (C: n=10) that did not participate in any resistance exercise program; a low-volume progressive exercise group (LV: n=12); and a high-volume periodized exercise group (HV: n=12). The LV group trained three times per week, performing a single set of each exercise, with 8-12 repetitions per set and two minute rest periods between sets. When the subject was able to perform 12 repetitions of an exercise, the resistance was increased for the next workout. The HV group trained four times per week, performing a non-linear periodized program. The subjects alternated between heavy (3-5 RM), moderate (8-10 RM), and light (12-15 RM) loads. Each workout consisted of three sets of each exercise at the prescribed load with 1-4 minute rest periods between sets, depending on the resistance load. The exercises performed in both programs included exercises for all of the major muscle groups. The subjects were tested at three time points: prior to the start of training (T1), after three months of training (T2), and at the completion of six months of training (T3). Testing included: anthropometric measures, body mass and percentage body fat, 1-RM strength in the bench press and leg press, muscular endurance in the bench press and leg press (repetitions at 80% of 1-RM), Wingate Anaerobic Power test and vertical jump, and analysis of resting serum testosterone, growth hormone and cortisol concentrations. Statistical evaluation of the data was accomplished by two-way analysis of variance with repeated measures with a Tukey post-hoc test performed when a significant F value (α=0.05), was detected.

RESULTS

None of the groups demonstrated a significant change in body weight over the course of the six months of training. However, both training groups significantly decreased percentage body fat, reaching significance by T2 in the HV group and T3 in the LV group. A consistent pattern developed in many of the performance variables. In the 1-RM bench press, 1-RM leg press, leg press repetitions, and vertical jump, both training groups made significant improvements from T1 to T2, however only the HV group made continued improvement from T2 to T3 (Table 1). In addition, a significant difference between the two training groups occurred by T2 for all four of these tests. In bench press repetitions, the LV group did not make a significant improvement until T3, while the HV group made significant improvement by T2, and again from T2 to T3. In the Wingate Test, the LV group did not make any significant improvement at any timepoint, while the HV group made significant improvements from T1 to T2 and from T2 to T3. Serum testosterone values showed a significant increase in resting values from T1 to T2 in both of the training groups, however only the HV group continued to show an increase from T2 to T3. No groups showed any changes in resting serum growth hormone concentrations over the training. The HV training group showed a significant decrease in resting cortisol by T3, but no other changes were significant.

Table 1: Results of some of the performance data for the LV and HV groups.

	Bench Press (kg)		Leg Press (kg)		Repetitions Bench Press		Repetitions Leg Press		Peak Power (Wx10)	
	LV	HV	LV	HV	LV	HV	LV	HV	LV	HV
T1	22±2	22±2	95±8	95±6	10±1	10±1	11±1	11±2	60±4	59±6
T2	25±2	27±1	104±7	115±7	10±1	11±2	13±1	15±2	60±5	67±6
T3	25±2	32±3	106±8	126±6	11±2	12±2	13±1	18±2	62±6	75±6

DISCUSSION

The main finding of this investigation was that a high-volume periodized resistance training program to elicit continued long term gains in performance parameters. Initially, subjects in both training groups made significant gains in most of the strength, power and endurance tests performed in this investigation. These gains are hypothesized to be initially due to neurologic adaptations in the neuromuscular system, including increases in neural activation of the agonists and/or decreases in co-activation of the antagonists and/or improved co-contraction of synergistic muscles. However, over time, the low-volume training program stopped providing adequate stimulus for continued gains in performance. The reasons for this are multifactorial. First, due to the lack of variation of the training program, the subjects may have suffered from a plateauing effect. Secondly, because the volume of stress on the muscle was low and did not change, the muscle adapted to the stress and failed to make continued gains in performance. The results of the current investigation are consistent with a previous study by Ostrowski et al. 1997, which demonstrated that men showed a higher testosterone to cortisol ratio after training in a multiple set training program when compared to a low-volume single set training program. It is also consistent with other studies which have shown that a high-volume training program could induce a decrease in resting serum cortisol and an increase in resting testosterone in women. These alterations in the hormonal balance of the body may help explain the increased anabolic effects of the high-volume, periodized training program.

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APPENDIX B

Manuscript (Miles et al., 1999)

Leukocyte adhesion molecule expression during intense resistance exercise

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Miles, Mary P., Sharyn K. Leach, William J. Kraemer, Keiichiro Dohi, Jill A. Bush, and Andrea M. Mastro. Leukocyte adhesion molecule expression during intense resistance exercise. *J. Appl. Physiol.* 84(5): 1604–1609, 1998.—We hypothesized that expression of L-selectin and very late antigen-4 (VLA-4) integrin adhesion molecules would influence cell type-specific redistribution during exercise. Women subjects performed six sets of 10-repetition maximum squats. L-selectin and VLA-4 integrin were measured by using flow cytometry pre- and postexercise on peripheral blood neutrophils and lymphocytes (n = 29 subjects) and lymphocyte subsets (n = 70 subjects), respectively. Neutrophil concentration increased 41.8% ($P < 0.001$), whereas the percent expressing L-selectin was unchanged (79%). Lymphocyte concentration increased 61.8% ($P < 0.001$). The percent of T cells expressing L-selectin decreased from 73.5 ± 8.9 to 68.2 ± 11.4% ($P < 0.001$); the combined population of natural killer and B cells expressing L-selectin decreased from 80.4 ± 22.5 to 62.7 ± 25.8% ($P < 0.001$). VLA-4 integrin was expressed by nearly all lymphocytes both pre- and postexercise. The proportional decrease in L-selectin positive cells could have resulted from *1*) shedding of L-selectin, *2*) selective entry of L-selectin-negative subsets, or *3*) selective removal of L-selectin-positive subsets.

very late antigen-4 integrin; L-selectin; neutrophils; lymphocytes; cortisol

EXERCISE CAUSES a redistribution of leukocytes that varies by cell type. Cell type-specific redistribution of leukocytes hinges on surface adhesion molecules. Expression and activation of several surface adhesion molecules by distinct leukocyte populations dictates cell type-specific adhesion in different tissues (7, 22, 24). The tissues to which cells will adhere, the stimuli that cause release into the circulation, and the stimuli that elicit extravasation are determined by the adhesion molecule profile of a given leukocyte type. Furthermore, the profile of adhesion molecules expressed on different leukocyte populations is influenced by systemic factors. For example, some adhesion molecules are upregulated, whereas others are downregulated, by cortisol (5, 6).

Adhesion is mediated by two general classes of molecules: selectins and integrins. Selectins are responsible for the slowing down and rolling of circulating leukocytes near sites of adhesion (7, 15). This slowing gives local chemotactic factors a chance to activate integrins that provide firm attachment to various ligands generally found on the endothelium (7). In this model for leukocyte migration to sites of inflammation, the two cellular adhesion molecules work in concert to achieve leukocyte adherence. Uksila et al. (24) demonstrated that leukocyte adhesion in different tissues for leukocyte storage was dependent on variable expression of many different adhesion molecules for cell type-specific adhesion. From this, we infer that release of leukocytes from sites of storage into the circulation also occurs in a specific manner according to the profile of adhesion molecules.

L-selectin and very late antigen-4 (VLA-4) integrin are among the many leukocyte adhesion molecules that influence the trafficking of leukocytes. L-selectin is expressed on many leukocytes and binds to carbohydrate structures on endothelial cells that are either in peripheral lymph nodes or activated by inflammation (15). The VLA-4 integrin is a β_1/α_4-subunit complex (CD49d) involved in directing the migration of leukocytes to inflammation and lymphoid tissues (11). Vascular cell adhesion molecule-1 and fibronectin are VLA-4 ligands. Reduced localization of leukocytes at sites of inflammation has been demonstrated in mice lacking L-selectin (7). Reduced lymphocyte adhesion to activated endothelial cells has been measured after VLA-4 blockade with antibodies (11). Thus, L-selectin and VLA-4 are important in leukocyte adhesion and may influence leukocyte redistribution during exercise.

Therefore, investigation of L-selectin and VLA-4 may help to elucidate the mechanism of differential recruitment of various leukocyte populations to the circulation during exercise. Exercise disproportionately influences trafficking of natural killer (NK) cells and granulocytes (see Ref. 17 for review). Adhesion by NK cells is particularly dependent on VLA-4 (10), and adhesion by neutrophils is particularly dependent on L-selectin (5, 6). Thus, VLA-4 integrin has particular relevance to the investigation of exercise and leukocyte adhesion molecule expression. We hypothesized that cell types entering the circulation preferentially during exercise would have a distinct profile of adhesion molecules compared with those cell types less affected by exercise. Consequently, the L-selectin and VLA-4 expression on circulating leukocytes would change to favor cell types entering the circulation during exercise. The purpose of this investigation was to determine whether the influx of neutrophils and lymphocytes during brief, heavy-resistance exercise changed the expression of L-selectin and VLA-4 on these two leukocyte populations (*experiment 1*) and on specific lymphocyte subsets (*experiment 2*). *Experiment 2* was carried out to follow up on the findings of *experiment 1*.

METHODS

Subjects. This investigation was approved by the Institutional Review Board for the Use of Human Subjects at Pennsylvania State University. Healthy women between the ages of 18 and 35 yr were recruited as subjects, and they gave written informed consent before participating. Two separate experiments were performed by using the same subject-testing protocol; 29 and 70 women participated in *experiments 1* and *2*, respectively. Descriptive data for both groups are given in Table 1.

Exercise. A brief, heavy, squat-resistance exercise was chosen for this investigation because it elicits quick and dramatic increases in exercise-related stimuli and provides a similar stress among subjects relative to their strength and body mass. At least 3 days before the squat-performance test, the one-repetition maximum (1 RM) for the squat exercise was determined for each subject. Subjects were coached in proper squat technique at this time. On the day of the squat-performance test, subjects reported to the laboratory between 630 and 1300 after at least 4 h of fasting. After the resting-condition blood sample was collected, subjects performed 2–3 min of low-tension stationary cycling as a warm up before beginning the squat exercise. The squat mass during the performance test was equal to 75% of the 1 RM. Subjects began in the fully upright position and lowered the weight until the femur reached a position parallel to the floor. Six sets of 10 repetitions were performed, with 2 min of active rest between sets. If subjects were unable to complete 10 repetitions within a set at the starting weight, a small amount of weight was removed for subsequent sets. The squat exercise and determination of 1 RM were performed by using a computerized Smith-like machine (Plyometric Power System, Lismore, New South Wales, Australia) previously described in detail (27). Completion of the squat-performance test took ~15 min.

Blood collection. Peripheral blood was collected from a forearm vein by using a 20-gauge needle and a standard venipuncture technique. Samples were collected immediately pre- and within 5 min postexercise into 5-ml vacuum tubes containing 0.5% EDTA anticoagulant (Becton Dickinson, Franklin Lakes, NJ). Two tubes were collected for the assays in this investigation: one for labeling leukocytes and one for complete blood count (CBC). Subjects were lying down during collection of blood pre- and postexercise.

CBC and cortisol determination. In *experiment 1*, CBC analysis was done by using an automated hematology analyzer (Coulter, Hialeah, FL) and a manual differential so that segmented and banded neutrophils could be distinguished. In *experiment 2*, the breakdown of neutrophil populations was not needed, and CBC analysis was done by using only an automated hematology analyzer with an automated differential. Serum cortisol was measured in duplicate by using a solid-phase RIA technique (Diagnostics Products, Los Angeles, CA). Inter- and intra-assay variances for cortisol were <6 and 4%, respectively.

Table 1. *Subject characteristics*

	Experiment 1	*Experiment 2*
n	29	70
Age, yr	22.9 ± 3.6	23.4 ± 4.2
Height, m	1.65 ± 0.07	1.66 ± 0.07
Mass, kg	61.3 ± 8.7	64.9 ± 10.1
Squat 1 RM, kg	52.3 ± 13.9	51.6 ± 11.2

Values are means ± SD; *n*, no. of women; 1 RM, 1 repetition maximum.

Leukocyte labeling. Within 6 h of collection, leukocytes were labeled for two-color analysis by using FITC- and phycoerythrin (PE)-conjugated monoclonal antibodies (Becton Dickinson Immunocytometry Systems, San Jose, CA) and a whole blood staining method. In *experiment 1*, CD62L-FITC and CD49d-PE were used to determine the percentages of lymphocytes and neutrophils bearing L-selectin and VLA-4, respectively. Additionally, CD3-FITC, CD19-PE, and CD16+56-PE were used to determine percentages of T, B, and NK (CD3−) lymphocytes, respectively. In *experiment 2*, additional stains, including CD3-FITC/CD49d-PE and CD3-PE/CD62L-FITC, were used to elucidate which lymphocyte subsets had VLA-4 and L-selectin adhesion molecule surface expression. A FITC- and PE-conjugated isotype control was used to determine background fluorescence. Bit-map gates based on cell size and granularity were used to distinguish lymphocytes and neutrophils for fluorescence analysis, and a CD45-FITC/CD14-PE stain was used to determine the purity of lymphocyte and neutrophil populations.

With a minor modification for the use of a new flow cytometer in *experiment 2*, the same double-labeled staining procedure was used for all samples. Briefly, 10 μl of a FITC-labeled and 10 μl of PE-labeled antibody, or 10 μl of a Simultest FITC and PE antibody pair, were pipetted into a tube, and 100 μl of whole blood were added, vortexed gently, and incubated for 20 min in the dark at 4°C. After incubation, 2 ml of FACSLyse (Becton Dickinson Immunocytometry Systems) solution were added to each of the tubes before vortexing and incubating for 10 min in the dark at room temperature for erythrocyte lysing. Tubes were centrifuged for 4 min at 250 *g*. The supernatant was vacuum aspirated, and the cells were washed with 1 ml PBS without magnesium or calcium, centrifuged, and vacuum aspirated again. The pellet was resuspended in a fixative solution of 1% formaldehyde in PBS without magnesium or calcium. In *experiments 1* and *2*, the samples were resuspended in 100 and 500 μl of 1% formaldehyde, respectively. Samples were refrigerated and stored until they were analyzed by flow cytometry, usually within 1 day, but always within 3 days of labeling.

From each stained sample in *experiment 1*, 10,000 events were collected by using an EPICS 753 flow cytometer (Coulter). Raw flow data were analyzed by using EPICS software (version 4.0, Coulter) to determine proportions of fluorescently labeled lymphocytes. In *experiment 2*, neutrophils were not analyzed, and 5,000 events within the lymphocyte-scatter gate were collected by using a model XL flow cytometer (Coulter). Raw data were analyzed by using Coulter System II (version 1.0, Coulter). Concentrations of cells with each surface marker were calculated by multiplying the neutrophil or lymphocyte concentration by the percentage with positive fluorescence for cell surface marker. To account for contamination by platelets and debris, we corrected lymphocyte percent by dividing the raw percent by the CD45+ proportion of the lymphocyte scatter gate. Neutrophil purity was generally >99%; therefore, no correction was necessary.

Flow cytometric analyses were reliable from test to test. To determine the reliability of the assay, two separate blood samples were collected from eight women in the resting condition. For the proportions of CD3+/CD62L+, CD3−/CD62L+, CD3+/CD49d+, and CD3−/CD49d+ lymphocytes, no differences were found between the first and second samples (paired *t*-test), and Pearson product-moment correlation coefficients were all greater than $r = 0.9$. To determine the test-retest reliability of the exercise response, we performed the same analyses for a sample of 10 of the subjects in

experiment 2 who repeated the exercise 3 mo later. No differences were found between the first and second blood samples from the resting condition or between the first and second postexercise samples, except for CD3+/CD62L+ lymphocytes (means were within 5% of each other). Pearson product-moment correlations for paired data from the two separate testing sessions ranged from $r = 0.67$ to $r = 0.77$. These data indicate that the measures used in this investigation were stable and consistent for test-retest within the same day for resting condition samples and on separate days for the exercise response.

Statistical analysis. Means ± SD were calculated. Differences between pre- and postexercise measures were detected by using Bonferroni alpha-corrected paired *t*-tests. Significance was set at alpha = 0.05.

RESULTS

Exercise increased ($P < 0.001$) the concentration of lymphocytes and neutrophils in both *experiments 1* and *2* (Table 2). In *experiment 1*, neutrophil concentration increased 41.8%, with a net increase of 1.71 ± 1.13 cells × 10^9/liter. Most neutrophils expressed L-selectin (CD62L+), and this percent did not change during the exercise (Table 3). Very few neutrophils expressed VLA-4 (CD49d−) pre- or postexercise. A small percent (21%) did not express either adhesion molecule. The concentration of CD62L+ neutrophils increased from pre- to postexercise ($P < 0.001$; Fig. 1).

In *experiment 2*, percentages of T, B, and NK lymphocytes in the resting condition were 74.7 ± 6.3, 8.8 ± 2.8, and 13.9 ± 7.2%, respectively. Although the majority of lymphocytes in the circulation at rest were T cells, the lymphocyte increase during exercise was attributable to roughly equal influxes of additional T and NK cells (Table 2).

Lymphocytes expressing either or both L-selectin and VLA-4 increased in concentration ($P < 0.001$) in *experiments 1* and *2*. To avoid duplication, only the data from *experiment 2*, in which additional lymphocyte parameters were measured, are presented. There was an increase ($P < 0.001$) in the concentration of lymphocytes expressing VLA-4 (Fig. 2). The percentage of lymphocytes expressing VLA-4 was ~95% pre- and postexercise (Table 3). The percentage of lymphocytes coexpressing VLA-4 and L-selectin decreased, as did the percentage of lymphocytes expressing only L-selectin ($P < 0.001$ for both). Thus, in contrast to neutrophils, there was a decrease in the percentage of lymphocytes expressing L-selectin. The decreased percentage of CD62L+ lymphocytes was a function of a decreased proportion of T cells and an increased proportion of NK cells postexercise (Fig. 3). The CD62L+ proportion of T cells (CD3+) and the combined B and NK cell population (CD3−) both decreased ($P < 0.001$). However, the concentration of all subsets expressing CD49d and or CD62L increased ($P < 0.001$) (Fig. 4). The change in concentration for subset populations indicates that the decrease in percentage of CD62L+ lymphocytes occurred because ~50% of the incoming cells were CD62L+ positive compared with 73.5 and 85.2% of CD3+ and CD3− cells at rest, respectively (Fig. 3).

The surface density of L-selectin was altered slightly on neutrophils but not on lymphocytes. In *experiment 1*,

Table 2. *Leukocyte concentrations*

Cell Type	*Experiment 1* (*n* = 29)		*Experiment 2* (*n* = 70)	
	Preexercise	Postexercise	Preexercise	Postexercise
Leukocytes	7.16 ± 1.42	10.80 ± 2.11*	6.80 ± 1.35	10.16 ± 1.97*
Neutrophils	4.09 ± 1.33	5.80 ± 1.86*	3.75 ± 1.28	5.32 ± 1.76*
Segmented	3.93 ± 1.30	5.69 ± 1.85*	NM	NM
Banded	0.16 ± 0.21	0.11 ± 0.15	NM	NM
Lymphocytes	2.45 ± 0.74	3.88 ± 0.96*	2.49 ± 0.72	4.03 ± 1.01*
T cells	1.84 ± 0.69	2.51 ± 0.80*	1.87 ± 0.58	2.60 ± 0.75*
B cells	0.32 ± 0.38	0.42 ± 0.45*	0.22 ± 0.10	0.30 ± 0.13*
NK cells	0.33 ± 0.28	0.94 ± 0.53*	0.35 ± 0.23	1.03 ± 0.39*
Monocytes	0.32 ± 0.22	0.54 ± 0.31*	0.58 ± 0.61	0.82 ± 0.78*

Values are means ± SD of concentrations (10^9/l); *n*, no. of women; NK cells, natural killer cells; NM, not measured. *$P < 0.001$ compared with preexercise.

Table 3. *Percentages of leukocytes expressing L-selectin and VLA-4 integrin*

Condition	L-Selectin Only, %	L-Selectin and VLA-4, %	VLA-4 Only, %
	Neutrophils (n = 29)		
Preexercise	78.6 ± 14.3	7.0 ± 5.9	0.8 ± 1.1
Postexercise	79.0 ± 16.8	6.7 ± 4.9	0.6 ± 0.7
	Lymphocytes (n = 70)		
Preexercise	5.8 ± 4.9	62.3 ± 8.1	32.4 ± 8.4
Postexercise	4.9 ± 2.2	50.1 ± 8.9*	44.5 ± 9.0*

Values are means ± SD; *n*, no. of women. VLA-4, very late antigen 4. *$P < 0.001$ compared to preexercise.

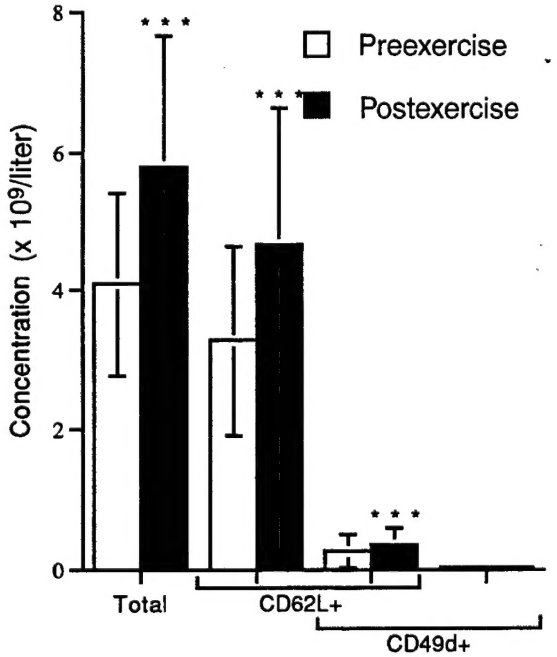

Fig. 1. Pre- and postexercise concentrations of total neutrophils and those expressing L-selectin (CD62L+/CD49d−), or very late antigen (VLA)-4 (CD62L−/CD49d+), or both (CD62L+/CD49d+) during heavy-resistance exercise. Values are means ± SD; *n* = 29 women. ***$P < 0.001$ preexercise compared with postexercise.

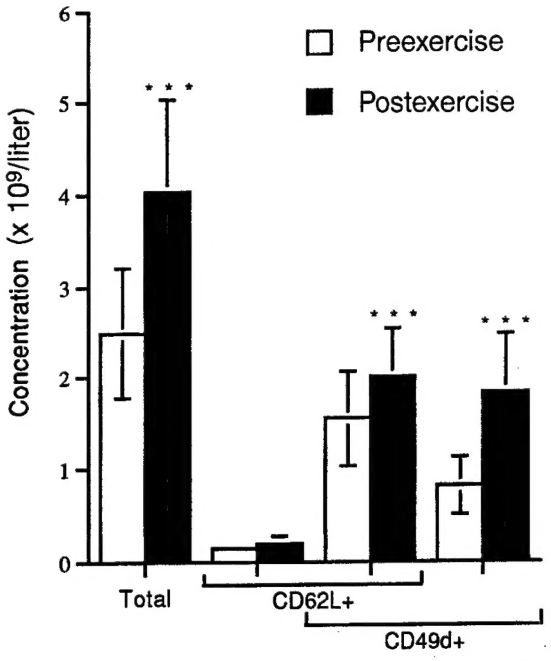

Fig. 2. Pre- and postexercise concentrations of total lymphocytes and those expressing L-selectin (CD62L+/CD49d−), or VLA-4 (CD62L−/CD49d+), or both (CD62L+/CD49d+) during heavy-resistance exercise. Values are means ± SD; n = 70 women. ***$P < 0.001$, preexercise compared with postexercise.

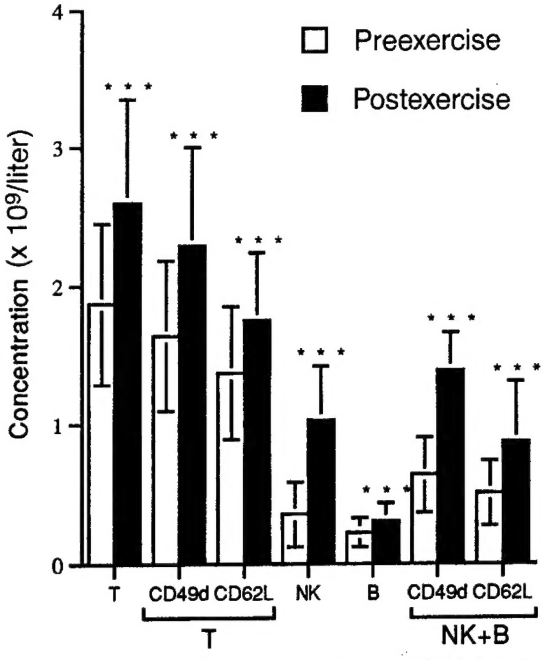

Fig. 4. Pre- and postexercise concentrations of T (CD3+), NK + B cells (together, CD3−) lymphocytes and corresponding changes in those subsets expressing VLA-4 (CD49d+) and L-selectin (CD62L+). Values are means ± SD; n = 70 women. ***$P < 0.001$, preexercise compared with postexercise.

the mean log fluorescence intensity of CD62L on neutrophils increased ($P < 0.05$) from 3.8 ± 1.1 to 4.0 ± 1.2 relative units on a three-decade log scale. In *experiments 1* and *2*, the mean log fluorescence intensity of CD49d or CD62L on lymphocytes did not change from pre- to postexercise.

Plasma cortisol concentrations were 984.9 ± 444.2 and 963.9 ± 433.9 μg/dl pre- and postexercise, respectively. The postexercise decrease was not significant.

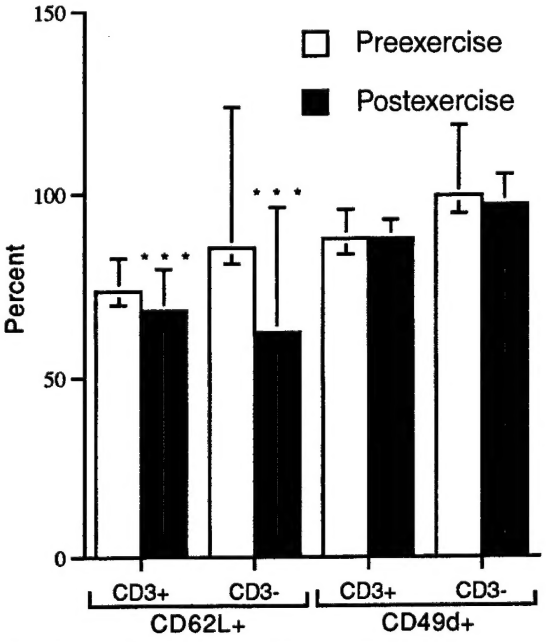

Fig. 3. L-selectin (CD62L+) and VLA-4 (CD49d+) expression on T cells (CD3+) and combined population of natural killer (NK) and B cells (CD3−) pre- and postexercise. Values are % of either CD3+ or CD3− populations that expressed L-selectin and VLA-4. VLA-4 was measured on >87% of CD3+ and on >96% of CD3− populations. Thus, most cells expressing L-selectin coexpressed VLA-4. Values are means ± SD; n = 70 women. ***$P < 0.001$ compared with preexercise.

DISCUSSION

Brief heavy-resistance exercise caused large increases in neutrophils and lymphocytes in the circulation. The same proportion of neutrophils, but a decreased proportion of lymphocytes, expressed L-selectin after the exercise. Neutrophils do not express VLA-4 (1), but the majority of lymphocytes measured in the circulation did express this molecule. The observed differences between neutrophils and lymphocytes are consistent with the model proposed by Spertini et al. (22), in which activation and deactivation of adhesion molecules occurs in a leukocyte lineage-specific manner.

The neutrophilia and lymphocytosis measured in this investigation are consistent with the findings of other investigations. Kraemer et al. (12) measured similar neutrophil responses to a comparable resistance-exercise protocol and found that these changes were not linked to elevations in cortisol. The concentration changes in lymphocyte subsets measured in this investigation are slightly lower than, but comparable with, those measured by Nieman et al. (16) in response to exhaustive resistance exercise in men.

The fluorescence intensity of L-selectin positive neutrophils increased, indicating that the surface density of this molecule was greater on cells in the circulation during exercise compared with those at rest. It is

thought that the immediate rise in neutrophils during brief exercise is a result of catecholamine-induced demargination, whereas delayed neutrophilia is stimulated by elevations in cortisol (19). Additionally, decreased neutrophil adhesion to endothelial cells in vitro has been linked to cAMP-induced changes in the endothelia (4). Although modest delayed neutrophilia has been measured in the absence of elevated cortisol (21), neutrophils appear to enter the circulation from the bone marrow by shedding L-selectin in response to increased cortisol (5, 6). The exercise in this investigation was brief, cortisol was not elevated, and banded neutrophils (indicative of bone marrow release) did not increase. These findings suggest that the neutrophil increase represents demargination. Thus, our data suggest that the density of L-selectin on marginated neutrophils was greater than on circulating neutrophils during resting conditions.

The percentage of T and combined NK and B cell populations expressing L-selectin decreased. L-selectin-negative NK cells entering the circulation could account for nearly all of the decrease in L-selectin expression within the NK and B cell population. Kurokawa et al. (13) found that the CD8+ T cells that increased in the circulation during exercise were L-selectin negative. The same occurrence was likely in the present investigation, because there was a strong positive correlation between L-selectin-negative T cells and CD8+ T cells ($r = 0.89$, $P < 0.001$, data not shown). Decreased percentages of lymphocytes expressing L-selectin could occur because L-selectin expression on these cells was less in the noncirculating pool, or because L-selectin was shed before entering the circulation or while in the circulation.

The possibility that L-selectin was shed could have been further investigated by measuring soluble L-selectin in the plasma. However, our data provide evidence that the interpretation of increases in soluble L-selectin should be made carefully. For example, while the surface density of L-selectin on neutrophils increased, the proportion of lymphocytes expressing L-selectin decreased, and the concentration of both neutrophils and lymphocytes expressing L-selectin increased. Neutrophils leaving the bone marrow shed L-selectin before entering the circulation (25), and neutrophils leaving the circulation shed L-selectin before extravasation (26). Thus soluble L-selectin elevations could result either from neutrophils or lymphocytes entering or leaving the circulation or from L-selectin shedding by either population while in the circulation. As a result, it would be extremely difficult to determine which of these events contributed to the increase in soluble L-selectin.

Our finding that 88% of T cells and at least 97% of the combined B and NK cell population expressed VLA-4 both pre- and postexercise cannot be used to suggest that lymphocyte trafficking during exercise is not influenced by this molecule. Adherence by VLA-4 (7) and other integrins (23) is altered by induced changes between low- and high-affinity conformations. In our investigation, discrimination between conformations of VLA-4 was not possible by using the CD49d antibody. Decreased NK cell adhesion (3) and increased NK cell concentration in the circulation (20) have been measured in response to β_2-adrenergic stimulation. β_2-Adrenergic stimulation can alter the density of several different adhesion molecules (20). However, in addition to finding the same surface density of VLA-4 before and after exercise, we also found that in vitro addition of L-epinephrine to whole blood did not change the density of VLA-4 (data not shown). However, vascular cell adhesion molecule-1, a primary VLA-4 ligand, can be activated by proinflammatory cytokines (9), indicating that changes to the epithelia also may play an important role in exercise-induced leukocyte trafficking. In addition to VLA-4, other β_1-integrins on NK cells include VLA-5 and VLA-6 (14), as well as Mac-1, lymphocyte function-associated antigen-1 (LFA-1), and p150/95 from the β_2-integrin family (13, 20). Thus it is likely that many adhesion molecules are involved in lymphocyte trafficking.

The general finding of several current investigations is that leukocyte adhesion molecule changes during exercise are related to localization at inflammatory sites. For example, lymphocytes with high expression of LFA-1, particularly NK cells, appeared to preferentially leave the circulation after prolonged endurance running that caused inflammation (8). Exercise training increased the expression of intercellular adhesion molecule-1, which may enhance localization to inflammatory sites (2). Muscle damage induced by high-force eccentric exercise was associated with increased Mac-1 expression on neutrophils and monocytes for 4 days (18). Adhesion by VLA-4 increased after stimulation with proinflammatory cytokines (9). VLA-4 was expressed on nearly all lymphocytes (present investigation), and stimulation by local proinflammatory cytokines can increase adhesion (9). Therefore, our VLA-4 data are consistent with mobilization of cells capable of responding to inflammatory stimuli. The decrease in L-selectin may be an indication that cells with this adhesion molecule actually may be leaving the circulation during exercise, similar to the decrease in cells with high expression of LFA-1 (8). However, this hypothesis has not been tested in either case, and the fate of these cells during exercise should not be speculated on without additional investigation.

In conclusion, we found that the proportion of neutrophils expressing L-selectin did not change during brief, heavy-resistance exercise. However, the surface density of L-selectin was greater for the neutrophils in the circulation after the exercise. These findings suggest that same proportion of expression, but a greater surface density of L-selectin on neutrophils, may be in the marginated pool. L-selectin expression decreased on T cells and on the combined B and NK cell population in the circulation. Potential mechanisms for enrichment of L-selectin negative lymphocytes in the circulation during exercise include the following possibilities: *1*) selective recruitment of cells not expressing L-selectin; *2*) selective removal of L-selectin positive lymphocytes from the circulation; or *3*) lymphocyte-

specific shedding of L-selectin. The expression of VLA-4 was high on nearly all lymphocytes, suggesting either that this molecule has no role in trafficking during exercise or that its role in trafficking is a function of a conformational change or of epithelial ligand activation.

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